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Editor's Note

The International Journal of Interactive Multimedia and Artificial Intelligence provides an interdisciplinary forum in which scientists and professionals can share their research results and report new advances on Artificial Intelligence and Interactive Multimedia techniques.

The research works presented in this issue are based on various topics of interest, among which are included: Mobile services, mpeg, agent-based Simulation, complexity, management accounting systems, animal-drawn vehicles, traffic and transport, possibility theory, precautionary saving, MAS, ambient intelligence, gamification, sustainable environments, disaster recovery, DSS, constraint programming and ICT.

López et al. presents the progress and final state of CAIN-21, an extensible and metadata driven multimedia adaptation in the MPEG-21 framework. CAIN-21 facilitates the integration of pluggable multimedia adaptation tools. To drive the adaptation, it uses the description tools and implied ontology established by MPEG-21. The paper not only describes the evolution and latest version of CAIN-21, but also identifies limitations and ambiguities in the description capabilities of MPEG-21 [1].

Friederike Wall investigates the effectiveness of reducing errors in management accounting systems with respect to organizational performance. In particular, different basic design options of management accounting systems of how to improve the information base by measurements of actual values are analyzed in different organizational contexts. The results provide broad, but no universal support for conventional wisdom that lower inaccuracies of accounting information lead to more effective adaptation processes. Furthermore, results indicate that the effectiveness of improving the management accounting system subtly interferes with the complexity of the interactions within the organization and the coordination mode applied [2].

Sánchez-Aparicio et al. analyzes the structure of the data collected in the population dependent or receives its revenues in the use of animal-drawn vehicle, to extract an economic model for the development of this activity introducing formal parameters, as well as replacement of the vehicle analyzes the development of this activity in this population [3].

Ana María Lucia Casademunt and Irina Georgescu study the optimal saving problem in the framework of possibility theory. The notion of possibilistic precautionary saving is introduced as a measure of the way the presence of possibilistic risk (represented by a fuzzy number) influences a consumer in establishing the level of optimal saving. The notion of prudence of an agent in the face of possibilistic risk is defined and the equivalence between the prudence condition and a positive possibilistic precautionary saving is proved. Some relations between possibilistic risk aversion, prudence and possibilistic precautionary saving were established [4].

Celia Gutiérrez proposes a framework that incorporates robust analysis tools using IDKAnalysis2.0 to evaluate bullying effect in communications. The work is based on ICARO-T. This platform follows the Adaptive Multi-agent Systems paradigm. Experimentation with ICARO-T includes two deployments: the equitative and the authoritative. Results confirm the usefulness of the analysis tools when exporting to Cooperative Multi-agent Systems that use different configurations. Besides, ICARO-T is provided with new functionality by a set of tools for communication analysis [5].

Silva et al. presents an approach which uses information from different environments, ranking them according to their sustainability assessment. Recommendations are then computed using similarity and clustering functions ranking users and environments, updating their previous records and launching new recommendations in the process. Gamification concepts are used in order to keep users motivation and engage them actively to produce better results in terms of sustainability [6].

Caianiello et al. outline a solution to the problem of intelligent control of energy consumption of a smart building system by a prosumer planning agent that acts on the base of the knowledge of the system state and of a prediction of future states. Predictions are obtained by using a synthetic model of the system as obtained with a machine learning approach. They present case studies simulations implementing different instantiations of agents that control an air conditioner according to temperature set points dynamically chosen by the user. The agents are able of energy saving while trying to keep indoor temperature within a given comfort interval [7].

Amadini et al., propose an approach that could be used as a decision support tool for a post-disaster response that allows the assignment of victims to hospitals and organizes their transportation via emergency vehicles. By exploiting the synergy between Mixed Integer Programming and Constraint Programming techniques, we are able to compute the routing of the vehicles so as to rescue much more victims than both heuristic based and complete approaches in a very reasonable time [8].

Juan Carlos Piedra Calderón and J. Javier Rainer explain the big influence of Information and Communication Technologies (ICT), especially in area of construction of Technological Societies. There are many changes that are visible in the way of relating to people in different environments. These changes have the possibility to expand the frontiers of knowledge through sharing and cooperation. That has meaning the inherently creation of a new form of Collaborative Knowledge. The potential of this Collaborative Knowledge has been given through ICT in combination with Artificial Intelligence processes, from where is obtained a Collective Knowledge. When this kind of knowledge is shared, it gives the place to the Global Collective Intelligence [9].

Guedes et al., proposes the definition of a system to negotiate products in an e-commerce scenario. This negotiation system is defined as PLANE – Platform to Assist Negotiation – and it is carried in a semi-automatic way, using

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multi-attributes functions, based on attributes of the negotiated content. It also presents an architecture to interconnect the participant through an inter-network in the television broadcasters context. Results demonstrated the success of the system in approximate the negotiator after some few interactions, reducing time and cost [10].

Dr. Rubén González Crespo

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CAIN-21: Automatic adaptation decisions and extensibility in an MPEG-21 adaptation engine

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***Abstract* — This paper presents the progress and final state of CAIN-21, an extensible and metadata driven multimedia adaptation in the MPEG-21 framework. CAIN-21 facilitates the integration of pluggable multimedia adaptation tools, automatically chooses the chain of adaptations to perform and manages its execution. To drive the adaptation, it uses the description tools and implied ontology established by MPEG-21. The paper not only describes the evolution and latest version of CAIN-21, but also identifies limitations and ambiguities in the description capabilities of MPEG-21. Therefore, it proposes some extensions to the MPEG-21 description schema for removing these problems. Finally, the pros and cons of CAIN-21 with respect to other multimedia adaptation engines are discussed.**

***Keywords* — ontology, multimedia, adaptation, decision, mpeg-7, mpeg-21**

I. Introduction

As time goes by, the variety of multimedia formats and devices has significantly increased, and still does. Multimedia content providers need to distribute their photos, videos and audio to a wide-range of devices and independently of the underlying delivery technology. *User-centric adaptation* [1] places the user in the centre of multimedia services and is also referred as *Universal Multimedia Experiences* (UME) [2].

The MPEG-21 standard [3] addresses the construction of a general multimedia framework that is consistent with the idea of UME. The MPEG-21 description tools enable the representation of a large set of concepts and relationships. MPEG-21 relies on the XML Schema to define the structure of the content and define an *implied ontology* in the text of the standard. Parts of the standards have been extended with description languages with a higher level of expressiveness. Particularly, the *explicit ontology* is represented using semantic description languages such as OWL (Web Ontology Language). The multimedia research com-munity has frequently accepted and used this MPEG-21 (pseudo)-ontology.

This paper compiles the evolution and final state of an adaptation engine named CAIN-21 [4] (Content Adaptation INtegrator in the MPEG-21 framework)[1]. The main purpose of CAIN-21 is to automate interoperability among multimedia formats and systems. Interoperability is implemented by means of an extensibility mechanism. With this mechanism, pluggable software tools are incorporated to progressively address wider ranges of adaptations. CAIN-21 automates interoperability by incorporating a decision mechanism for multimedia adaptation. This mechanism selects the adaptation tools and parameters that have to be executed to adapt multimedia. Furthermore, CAIN-21 exploits multi-step adaptation. Multi-step adaptation enables the combination and execution in several steps of the pluggable adaptation tools. With multi-step adaptations the range of feasible adaptations that can be achieved increases.

CAIN-21 also aims to provide a framework in which multimedia adaptation tools can be integrated and tested. The representation of the multimedia elements has to be formalized in order to make these tests[2] repeatable. To represent the multimedia elements of the tests, a set of MPEG-21 description tools have been selected. Currently, MPEG-21 is the most comprehensive multimedia description standard for the deployment of multimedia applications/systems. However, in practice description standards never cover 100% of the concepts. In the case of CAIN-21, we have encountered some difficulties using the MPEG-21 description elements. These difficulties were solved extending the description tools and implicit ontology that MPEG-21 provides. After presenting CAIN-21 architecture, this paper discusses these issues. We consider helpful to highlight it for people involved in the construction of multimedia adaptation systems, especially if they are determined to provide MPEG-21 interfaces to their users. The clarification of these problems may also be useful for people who intend further interaction with other non-MPEG-21 compliant multimedia systems.

The publication in [4] summarizes the interfaces, the architecture of CAIN-21, and the evolution from Early CAIN to CAIN-21, and provides a preliminary comparison with other

[1] The *CAIN-21 software* together with a *CAIN-21 demo* are publicly available at *http://cain21.sourceforge.net*

[2] This paper demonstrates our proposal with an empirical study. We use the term *test* (instead of *experiment*) to indicate that its execution always yields the same results.

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adaptation engines. Now that CAIN-21 has reached a stable and mature state, this publication supersedes [4] by providing an extended, comprehensive and updated description of CAIN-21.

In particular, this new publication describes the delivery and adaptation methods used in CAIN-21 as well as the binding modes. The publication also describes and provides usage examples of the *ConversionCapabilities* and *ConversionCapabilities* description tools, incorporates the properties relationships, the KISS principle behind this design, the use of composed properties to address complicated relationships, and proposes new ideas, such as the distinction between implied and explicit ontologies and the advantages of considering MPEG-21 as a simple (pseudo)-ontology. The updated multimedia adaptation engines comparison in Section VI adds *ConversionLink* to the comparison, adds new aspects to the comparison (i.e., multistep, extensibility and semantic adaptation), discusses the reasoning behind the different approaches taken over the years and the pros and cons of the different decision methods. Finally, this publication appends several tests that illustrate the multimedia adaptation method proposed in this paper, and justifies the need for the proposed extensions to the MPEG-21 standard.

In the rest of this paper, Section II reviews the state of the art concerning semantic web description and the description tools that MPEG-21 provides for multimedia adaptation. It also introduces some automatic multimedia adaptation techniques. Section III describes the main features and elements of CAIN-21. Section IV offers innovative description tools that fill the description gaps identified in the standard and justifies their usefulness. Section V provides a set of tests that demonstrate and validate these extensions. Section VI provides a comparative analysis between CAIN-21 and other multimedia adaptation engines. Finally, Section VII gathers the innovations and advantages of the adaptation techniques explained in the paper and it provides some conclusions.

II. State of the art

A. Semantic web for multimedia

The Semantic Web [5] aims to represent knowledge in a format that can be automatically processed without human intervention. For this purpose the machine must be capable of understanding the concepts and relationships thereby described. The *Semantic Web Stack* [5] defines a stack of languages in which each layer uses the description capabilities of the layer below it to provide a higher level of expressiveness. In this stack, the technologies up to RDF, OWL and SPARQL have been standardized and accepted. The term *ontology* is used to refer to the concepts (usually defined with a formal *vocabulary*) and relationships in a specific domain. This ontology is frequently represented with OWL creating a *semantic graph*. The technologies in the top of the stack use the semantic graph to infer additional knowledge. Currently, it is not clear how to implement the technologies on the top of the stack. Automatic reasoning has been frequently proposed to infer this additional knowledge. However, the results of these top-level technologies are still limited to achieve the ultimate aim of the Semantic Web: the sharing, processing and understanding of data by automatic systems in the same manner that people can do.

To build a multimedia system that automatically manages and understand multimedia content, it is crucial to define the ontology of its multimedia concepts: Fig. 1 depicts this idea. Bold lines represent better levels of understanding. The figure shows that the user is capable of understanding the meaning of the media, but has more difficulties reading the description of the content. For instance, it is easier for the user to identify a dog in a picture than to interpret its MPEG-7 description [6]. On the other hand, the computer can extract information from metadata more easily than it can analyse the corresponding media resource.

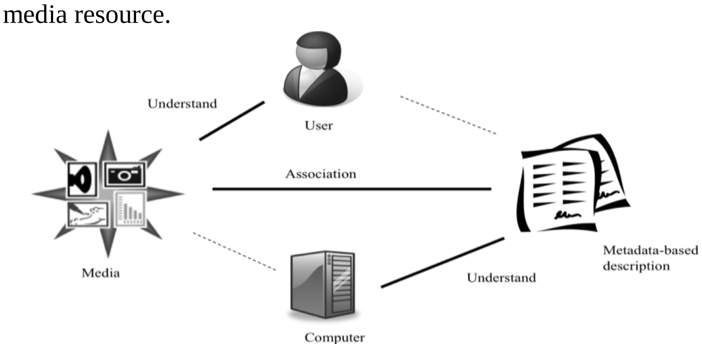

Fig. 1: Semantic description of multimedia content

In the field of multimedia, two widely accepted implied ontologies are the MPEG-7 [6] standard for the media content and MPEG-21 [3] for the whole multimedia system. These standards make use of metadata to achieve a better understanding of multimedia. Particularly, these standards propose several vocabularies to represent a detailed description of the meaning of the multimedia elements. MPEG-7 and MPEG-21 tend to define the external interface of the multimedia systems and leave the algorithms that implement it (e.g. reasoning) to the industry and research community. The W3C Consortium has also initiated a project to represent multimedia ontology called *Multimedia Vocabularies on the Semantic Web* [7]. Even although this standard fully exploits OWL, which has a higher level of expressiveness and ability to represent knowledge, at time of writing, the majority of multimedia research relies on MPEG-7 and MPEG-21.

B. MPEG-21

This section reviews the state of the art for the MPEG-21 description tools to which this paper contributes. A complete description for the MPEG-21 standard can be found in [3].

1) Content description and conditional elements

The notion of *Digital Item* (DI) is a fundamental concept within MPEG-21. A DI is a general representation for any multimedia element. This element can represent both the multimedia content and the multimedia context. MPEG-21 Part 2 [3] standardises the representation of a DI in the case of multimedia content. A DI may contain one or more *Component*[3] elements. Each *Component* includes one *Resource* element and zero or more *Descriptor* elements. The *Resource* element references the media and the *Descriptor* element provides metadata for this media. The MPEG-21 allows optional, alternative and conditional elements. For the purposes of this paper we are only going to describe conditional elements. A *conditional element* is an element of the DI that appears only when certain conditions are true. Certain elements of the DI are configurable, i.e., their content varies depending on the value of *Predicate* elements. A *Predicate* element can take the values *true*, *false* or *undecided*. The *Choice* element enables a "menu". The options of this menu are provided through *Selection* elements. The *Selection* elements are used to define in runtime the values of the *Predicate* elements. The MPEG-21 standard does not define how the values of the *Predicate* elements are obtained. These values can be asked to the user or automatically decided by the multimedia system. The value of some *Predicates* can be even unknown in runtime, in which case they take the *undecided* value. A *Condition* is a conjunction (and operator) of one or more predicates. The *Condition* elements are used to specify which elements of the DI are valid in runtime. Only the elements for which the *Condition* is true are considered part of the DI. For instance, several *Component* elements may contain a *Condition* element. In runtime, only the *Component* whose *Condition* is true is considered part of the DI.

2) MPEG-21 adaptation tools

MPEG-21 Part 7 [3] has defined a set of *description tools* (or merely *tools*) for multimedia adaptation. These tools do not specify how the adaptation has to be performed; they only gather the information necessary for adapting a DI. These tools are collectively referred as *Digital Item Adaptation* (DIA) *tools*. The instances of these tools are referred as DIA *descriptions* (or merely *descriptions*). This section reviews the *Usage Environment Description* (UED) tools, the *DIA Configuration* tools and the *ConversionLink* tools.

3) UED tools

These tools enable the description of the terminal capabilities, the network constraints, the user's characteristics, preferences and natural environment. The term *usage environment description* (or merely *usage environment*) refers to an instance of one or more *UED* tools. Further description of the *UED* tools can be found in [3].

4) DIA Configuration tools

The DI author can use the *DIA Configuration* tools to recommend how to adapt the content to the usage environment. Specifically, the *DIA Configuration* tools include two tools to drive the adaptation. The first tool allows the DI author to indicate how to obtain the options of the *Choice* conditional mechanism explained above. For this tool, the standard defines only two values: *UserSelection* indicates that the selection has to be done by the user. *BackgroundConfiguration* indicates that the system has to automatically perform this decision.

The second tool is the *SuggestedDIADescription*. The DI author uses this tool to point out which parts of the DI or DIA descriptions have to be used to decide the adaptation. Specifically, XPath [8] expressions are used to provide this information. For instance, the DI author may recommend using the *Format* element of the *VideoCapabilitiesType* in the *UED* to make the adaptation decision. A further description of these tools can be found in [3].

5) ConversionLink tools

The *ConversionLink* tools appear in [9] to complement the *BSDLink* tools. The *ConversionLink* tools are intended to address generic adaptation (e.g. transcoding, transmoding, summarization) whereas the *BSDLink* are intended for scalable bitstream adaptation. The MPEG-21 standard defines a *conversion* as a processor (software or hardware) that changes the characteristics of a *Resource* or of its corresponding *Descriptor* elements. The *ConversionLink* tools include the *ConversionCapabilitiesType* tool. This tool expresses the types of conversions that a terminal is capable of performing. The content of this tool is not standardised, instead, it provides a derivation-by-extension mechanism allowing the inclusion of conversion descriptions. A further description of these tools can also be found in [10].

C. Multimedia adaptation-decision making methods

Typically, multimedia adaptation is performed in two phases, which usually execute in a sequential manner [11][13][14][15]. Firstly, a *decision phase* is used to evaluate which adaptations best suits the constraints of the usage environment. Secondly, in the *execution phase*, these conversions are performed on the media and metadata conveyed in the DI. For the decision phase, two different methods have been widely investigated in the literature:

1) Quality-based methods [11][12][13] (also referred as *optimisation-based methods*) aim at finding the adaptation parameters that maximise the quality (also referred to as *utility*) resulting from the adaptation to the constraints of the usage environment. These methods operate by solving an optimisation problem in the Pareto frontier. Frequently, the MPEG-21 Part-7 DIA tools have been used to point out these relationships between the adaptation parameters and corresponding utilities.

2) Knowledge-based methods [14][15][16] have been used primarily to determine whether a conversion can be executed and which parameters must be supplied to adapt the content. These methods usually consider the concatenation of several conversions in a sequence. They have also been referred as multi-step adaptation.

[3] MPEG-21 capitalises and italicises XML description tools. This paper adopts this rule.

CAIN-21 (described in Section III) combines both methods in sequence. Firstly, the knowledge-based methods use the media format to decide which conversions have to be carried out in order to adapt the content to the usage environment. This method is further explained in [17]. Secondly, certain "intelligent" conversion tools incorporate the capability to select the parameters that optimise their output. The quality-based methods that CAIN-21 incorporates are demonstrated in [18].

D. Related multimedia adaptation engines

This subsection introduces related multimedia adaptation engines. Section VI compares these adaptation engines with CAIN-21.

Mariam [10] has studied the applicability of a standard *AdaptationQoS* description tool to drive general (scalable and non-scalable) resource adaptation. This investigation concludes developing the ConversionLink[4] adaptation engine togueter with the *ConversionLink* description tool. The *ConversionLink* tool was later standardized in [9]. This tool has already been described in Subsection II.B.

Debargha et al. [11] explained the basis of the *AdaptationQoS* description tool and its usage. Christian et al. [12] builds on this description tool to implement the idea of coded-independent resource adaptation for scalable resources. To this end, they have researched the *BSDLink* tools (introduced in Subsection II.B). In [12] they explains the use of the notion of Pareto optimality and multi-attribute optimisation to identify the scalable layers that best suit the terminal constraints [16].

Jannach et al. [15] developed the koMMa framework in order to demonstrate the use of Artificial Intelligence planning in multistep multimedia adaptation. They exploited Semantic Web Services to address interoperability. They also proposed an extensibility mechanism by means of pluggable Web Services.

Anastasis et al. describe the DCAF adaptation engine in [20]. This research showed how to use heuristic genetic algorithms to identify the parameters of the *AdpatationQoS* description tool. The *UED* and *UCD* description tools are used to represent the context of the adaptation. The notion of Pareto optimality is also introduced to rank the possible decisions.

Davy et al. [21] have built on the aforementioned *AdaptationQoS*, *BSD* and *UED* description tools to develop the NinSuna adaptation engine. This engine provides both coding-format independence and packaging-format independence. The major innovation of this engine is leveraging Semantic Web technologies to accomplish semantic adaptation decisions. The semantics are explicitly represented with RDF tuples and in this way they introduce formal semantics in the exiting MPEG-21 adaptation description tools.

[4] Note that the symbol ConversionLink is not italicized to refer to the adaptation engine. However, it is italicized to refer to the description tool.

E. Delivery and adaptation methods

From the standpoint of the media client, there are two main media *delivery models* [22]: *download*, where the client starts to play the media content after completely receiving the media from the server, and *streaming* where media content is played while data reception is in progress. *Streaming servers* usually cover two methods to deliver video to the users:

1) Live video. Broadcast of live events in real time. This streaming is useful when the client expects to receive video as soon as it is available. Live events, video conferencing, and surveillance systems are commonly streamed over the Internet as they happen with the assistance of broadcasting software. The video recording software encodes a live source (video or audio) in real time and transfers the resulting media to the streaming server. The streaming server then serves, or "reflects", the live stream to clients. Regardless of when different customers connect to the stream, each sees the same point in the stream at the same time.

2) Video On Demand (VOD). Each customer initiates the reception of the media from the beginning, so no customer ever comes in "late" to the stream. For instance, this mode can be used to distribute movies to users who play those movies at different times.

According to the moment at which the adaptation takes place; media adaptation can be divided into three *adaptation modes*:

1) Offline Adaptation mode (*OffA mode*). The adaptation is performed in the background and before the media is available to the user. This mode is adequate for on demand media delivery. However, this mode is not suitable for live video because the user is expecting to watch the video event as soon as it occurs. This adaptation requires previous knowledge of the feasible terminal capabilities and network bandwidth. The media can be prepared for several terminals of network capacities. The main limitation of the OffA mode is that the user's preferences and natural environment constraints are not taken into account. These parameters are unknown when the media repository is created. While creating a repository of adapted resources for each user's profile is possible, it is unmanageable from a practical point of view when the number of user's profiles increases.

2) On Demand Adaptation mode (*OdA mode*). Adaptation takes place at the same time that the user asks for the resource. In this mode, the client's characteristics, preferences and natural environment can be taken into account. However, if the resource adaptation process is time consuming, the user has to wait until the whole resource is adapted. Therefore, this adaptation results useful for small resources (e.g. images), but can become unacceptable for long resources (e.g. video or speech).

3) Online Adaptation Mode (*OnA mode*). As with the OdA mode, user's characteristics, preferences and natural environment can be taken into account. In this mode also the adaptation begins as soon as the user asks for the resource. However, in contrast to the OdA mode, in the OnA mode the resource begins to be delivered to the user before the whole resource has been adapted. This adaptation is appropriate for long resources (and perhaps also for small resources). The drawback of this approach is that, in general, implementing this solution efficiently is difficult. In OnA mode we need to ensure that media data fragments are delivered to the client in time to maintain playback continuity. The advantage is that once implemented, the OnA mode can be reutilized to simulate the OffA and OdA modes.

III. CAIN-21: System description

This section sequentially describes the CAIN-21 software interfaces, the architecture and the control flow. Section IV builds on this section to specify the description tools that CAIN-21 utilizes and justifies their extension.

A. Software interfaces

CAIN-21 serves adaptation requests through two external software interfaces (see Fig. 2 below): (1) The *media level transcoding interface* performs *blind adaptation* (i.e. semantic-less adaptation) of a media resource. In addition to the media level, this interface can also perform system level adaptation, i.e., videos composed of one or more audio and visual streams. The media level transcoding operations are implemented in the *Tlib* module. This module includes conventional software libraries such as *ffmpeg*, *imagemagick* as well as Java Native Interface (JNI) custom libraries. (2) The *DI level adaptation interface* is in charge of performing system level (semantic or blind) adaptations. In this case metadata is used during the adaptation.

The DI level adaptation interface complies with the MPEG-21 representation schema. The *Content DI* conveys the media resource together with its metadata to be adapted. To drive the adaptation, CAIN-21 uses four *DIA* description tools. Only the *Content DI* and *DIA* description tools follow fully the MPEG-21 recommendations. For the point of view of these interfaces, CAIN-21 is a replaceable black box. Fig. 2 provides a view of CAIN-21 consistent with the idea of an adaptation engine that the MPEG-21 Part-7 framework proposes.

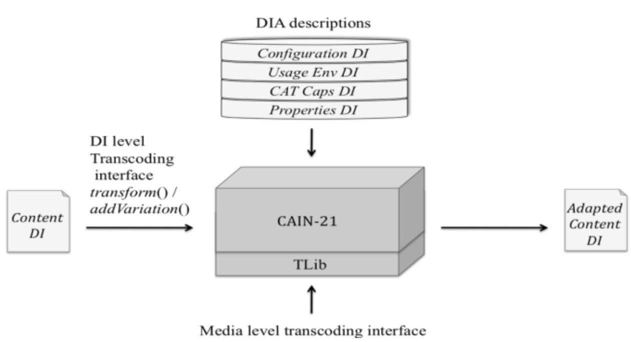

Fig. 2: Software interfaces of CAIN-21

In CAIN-21, metadata-based adaptation [23] is performed through the DI level interface and at the *Component* level. An MPEG-21 *Component* includes a media resource (in the *Resource* element) and its metadata (in the *Descriptor* element). The *Descriptor* elements use MPEG-7 Part 3, Part 4 and Part 5 [6] to describe the multimedia content. The DI level adaptation interface provides two different operations. The first one modifies the existing *Component* and the second operation adds a new *Component* element to the DI. More specifically: (1) the *transform*() operation takes a *Component* from the *Content DI* and modifies its media resource and metadata in order to adapt it to the usage environment; (2) the *addVariation*() operation takes a *Component* from the *Content DI* and creates a new *Component* ready to be consumed in the usage environment. At the end of this adaptation, CAIN-21 adds this adapted *Component* to the *Content DI*.

B. Architecture

This section provides a detailed description of the CAIN-21's modules. Fig. 3 depicts CAIN-21's functional modules and the control flow along the adaptation process. The rest of this subsection explains the modules and description tools in the figure.

1) Adaptation Management Module (AMM)

The AMM is responsible for coordinating the entire DI level adaptation process. Modules below the AMM perform different tasks initiated by the AMM.

2) Adaptation Decision and Execution Modules (ADM and AEM)

Subsection 8.C explained that frequently adaptation engines divide the decision and the execution into two different phases. Firstly, a decision phase is used to decide which adaptation best suits the constraints of the usage environment. Secondly, in the execution phase, these adaptation actions are performed on the media conveyed in the DIs. CAIN-21 also includes this distinction implemented in the *Adaptation Decision Module* (ADM) and the *Adaptation Execution Module* (AEM), respectively.

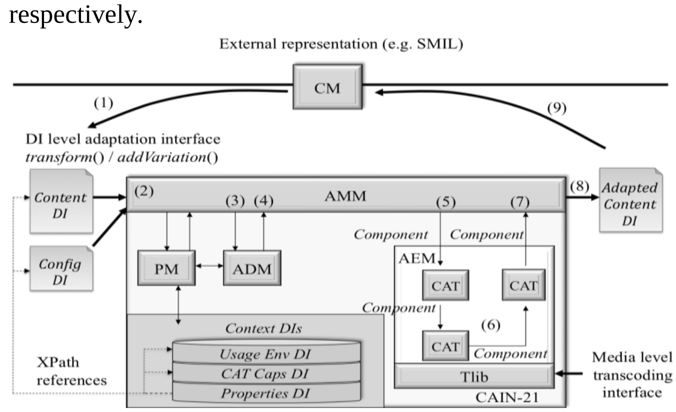

Fig. 3: Modules and control flow within CAIN-21

3) Conversions and Component Adaptation Tools (CATs)

As explained in Subsection II.B, MPEG-21 Part-7 defines a *conversion* as the process that changes the characteristics of a resource. In general, a conversion performs the act as defined by the MPEG-21 Part-6 term *adapt*. In CAIN-21, a

Component Adaptation Tools (CATs) is a pluggable software module that implements one or more conversions. Multi-step adaptation allows for the sequential execution of the conversions implemented in one or more CATs. The ADM uses metadata to determine the sequence of conversions and parameters that should be executed over a *Component* element of the *Content DI*. Subsequently, the AEM executes such sequence of CATs on the original *Component*. When a CAT is executed, both the conversion to execute and the parameters of the conversion have to be provided. If CAIN-21 receives multiple requests to adapt the same content to the same usage environment, a caching mechanism speeds up this process by bypassing the execution of the Planner and Executer several times.

During their execution, CATs have the option of appending information to the *Descriptor* element of the *Component* so that subsequently CATs can use it. We use the name *static decisions* to refer to metadata-based decisions. Static decisions do not depend on the resource content (only the *Descriptor*) and the ADM is responsible for these decisions. On the contrary, we use the term *dynamic decisions* to refer to adaptation decisions that perform operations over the resource content. Dynamic decisions cannot be taken until the resource is available and the CATs take them. These dynamic decisions usually correspond to semantic decisions or quality-based decisions. Frequently semantic decisions assume particular content (e.g. faces, soccer, news items, violent scenes in the movie). For example, in [19] we assume the existence of faces in the images. Quality-based decision methods have been described in Subsection II.C and demonstrated in [18].

4) Context Repository

As further described in Subsection IV.A, CAIN-21 defines a type of DI referred to as *Context DIs.* These *Context DI* elements store *DIA* descriptions with information concerning the context in which the adaptation takes place.

The *Context Repository* in Fig. 3 includes the three *Context DIs*. The *Usage Environment DI* describes the available usage environments using several MPEG-21 *UED* elements (i.e. instances of the *UED* tools). Each *CAT Capabilities DI* describes the different *conversions* that a CAT is able to perform. Each conversion has a set of valid input and output properties along with their corresponding values. The relationships among these elements are described in more detail in Subsection IV.C.

CAIN-21 includes an addressing mechanism in which changes in the metadata descriptors will not imply changes in the underlying source code. This mechanism is described in detail in Subsection IV.E. The mechanism represents all the multimedia information by means of *properties*. Each property has one *key* and one or more *values*. The advantage of this representation is that it suits the decision mechanism that we have developed for CAIN-21 [17]. The *Properties DI* is intended to store a set of keys and corresponding *xpointer*() [24] expressions providing access to the actual values. In Fig. 3, dashed arrows indicate that the *xpointer*() expressions in the *Properties DI* are stored in the other DIs.

5) Configuration DI

The *Configuration DI* is a *DIA* description indicating which description of the terminal, network and user – from the ones available in the *Usage Environment DI* – to use during a adaptation request. Subsection II.B explained that MPEG-21 recommends using the *Choice* descriptor and *DIA Configuration* description tool to specify the adaptation to perform. CAIN-21 does not use this standard mechanism; instead it uses the *Configuration DI* to indicate the parameters of the adaptation to perform. Subsection IV.A justifies this change and explains the advantages that this proposal yields.

6) Parsing Module (PM)

The PM is responsible for resolving the values of the aforementioned properties. Firstly, the PM accesses the *Properties DI* to obtain the set of property keys and corresponding *xpointer*() expressions. Secondly, after resolving these expressions, the values of these properties are generated. During this step, the rest of the metadata is loaded from the *Content DI*, *Configuration DI*, *Usage Environment DI* and *CAT Capabilities DI*. After parsing the different DIs, all the metadata is represented as a set of properties. The value of these properties can be multi-valued (e.g. *bitrate* = [1000..200000], *audio_format* = {*aac*, *mp3*}).

7) Coupling Module (CM)

A wide range of multimedia representation standards exists to represent multimedia content (e.g. HTML, SMIL, NewsML, MPEG-4 BIFS). CAIN-21 can be integrated into heterogeneous multimedia systems that may be using external representation technology (i.e., non-MPEG-21 technology). The CM is the gateway that enables such integration. To this end, this module transforms the external representation of multimedia into an MPEG-21 compliant input *Content DI* that afterwards CAIN-21 processes. In addition, the CM is responsible for transforming the adapted output *Content DI* into its external representation. Instances of the CM are interchangeable modules created to interact with different external representations. In practice, there is a semantic gap during this interaction with the external multimedia description standards, i.e., a direct correspondence between the external descriptors and the MPEG-7/21 descriptors might not exist. To provide these additional meanings, MPEG-7 Part 5 offers a set of open *Classification Schemes* (CSs) [6], which indicates what these external descriptors mean.

C. Control flow

The numbers in Fig. 3 indicate the control flow of the tasks in the adaptation process. (1) When interacting with external systems, the CM transforms the external multimedia representation into a *Content DI* that CAIN-21 can process. (2) The *Content DI* together with a *Configuration DI* arrives via the DI level interface *transform*() or *addVariation*() operations. (3) The AMM is in charge of coordinating the whole DI level adaptation process. Specifically, the AMM invokes in sequence the ADM and the AEM to (4) decide and (5) execute the corresponding adaptation on the original *Component*. (6) The CATs use the *TLib* services to adapt the media resource. The CATs might also change or append information to the *Descriptor* element of the *Component* so that the subsequent CATs may use it. (7) Once all the conversions of the sequence have been executed, (8) the AMM returns the adapted *Content DI* to the caller. (9) Frequently, the adapted *Content DI* may need to be transformed to an external representation and in this case, the CM performs this transformation.

IV. CAIN-21'S EXTENSIONS TO THE MPEG-21 SCHEMA

CAIN-21 uses the description tools that MPEG-21 standardises. The following subsections identify a set of limitations and ambiguities in the description capabilities of MPEG-21. They then propose some extensions to the MPEG-21 description schema. The additions are justified in order to remove these limitations and ambiguities. The following subsections also discus how these extensions make possible to address a new range of multimedia adaptation problems.

A. Content DI, Context DI and Configuration DI

Subsection II.B explained that in MPEG-21 framework different DIs are used throughout the consumption and delivery chain. The DIs can be classified according to their purpose. One initial approach in the literature has divided the DIs into *Content DI*s and *Context DI*s. The *Content DI* is a DI intended to carry out the multimedia resource and corresponding metadata. The *Context DI* is intended to contain a description of the usage environment. The notions of *Content DI* and *Content DI* have been considered by the MPEG-21 standard (see for instance [25]) although they have not been finally incorporated to the standard. However, some authors have informally used these notions in their systems [26][27].

Particularly, these authors have used the term *Context DI* only to reference the usage environment [25][26][27]. In [28], we proposed to extend the idea of *Context DI* to represent the context information. Particularly, in CAIN-21 there are three types of context elements: the *Usage Environment DI*, the *CAT Capabilities DIs* and the *Properties DI*. Subsection III.B described these elements.

Furthermore, CAIN-21 configures the adaptation using the *DIA Configuration* description tools (described in Subsection IIII.B). After an adaptation request, the *DIA Configuration* tools can be used to specify the target usage environment. Although there are scenarios in which the *DIA Configuration* tools is applicable, we have identified two limitations in the standard *DIA Configuration* mechanism:

1. The standard *Content DIs* uses the *Choice* description element to enclose alternative adaptation options, which depends on the available terminals. This produces a dependency between the *Content DI* (which contains the *Resource* and optionally a *DIA Configuration* description) and the *Usage Environment DI*. This dependency implies changing the *Content DI* whenever the *Usage Environment DI* is modified (e.g. one of the terminal descriptions is changed).

2. *DIA Configuration* assumes that the entire usage environment is known when the *Usage Environment DI* is created.

The idea of using three DIs avoids the first limitation:

1. The *Content DI* with the multimedia resource and corresponding metadata.

2. The *Context DI* that acts as a database where usage environment, adaptation capabilities and metadata properties under consideration are stored.

3. The *Configuration DI* that includes a *DIA Configuration* description.

The *Configuration DI* also solves the second limitation: the *Content DI* and the *Context DI* are created and stored in CAIN-21 during its development or deployment. The *Configuration DI* is dynamically created to provide to CAIN-21 information about the adaptation request to be performed.

Next section describes the *ARC* description tool that the *Configuration DI* conveys. The main aim of our proposal is that the *Content DI* will not be modified when the *Usage Environment DI* changes.

B. The ARC description tool

Section IIII.B described the two *DIA Configuration* description tools that MPEG-21 Part 7 standardises: (1) The *UserSelection*/*BackgroundConfiguration* elements indicate whether the DI *Choice*/*Selection* mechanism must be presented to the user or automatically decided by the system. (2) The DI's author uses the *SuggestedDIADescriptions* to suggest which *DIA Description* elements should be used for the adaptation. Both methods assume the existence of a negotiation mechanism. Authors such as [26][29] have followed this approach incorporating the *DIA Configuration* description in the DI to be consumed. CAIN-21 is not a network agent (as in the *DIA Configuration* usage model developed in [3]) but a middleware providing an API. Previous subsection introduces the problem of selecting zero or one instance of the standard MPEG-21 Part 7 *UED* description tools (i.e., *Terminal*, *Network* and *User*[5] elements) from the *Usage Environment DI*. If we relax the network agent negotiation assumption we can utilise the *DIA Configuration* to specify the particular usage environment. CAIN-21 extends the *DIA Configuration* to provide this information, i.e., it defines a third *DIA Configuration* tool (non-considered in MPEG-21). This extension is called *Adaptation Request Configuration* (*ARC*) tool. Consider, for instance, two terminals in the *Usage Environment DI*, a mobile terminal and a laptop terminal. In this case, an *ARC* description can be used to indicate the target terminal. The *Content DI* and the *Usage Environment DI* can be deployed before starting the adaptation engine. On the contrary, the *ARC* description is only created

[5] Currently CAIN-21 does not consider the *NaturalEnvironment* description tool, but its inclusion would be a direct process.

when an adaptation is going to be executed.

C. CAT Capabilities

The large quantity of multimedia adaptations that could be envisioned makes it unfeasible to implement all of them. Subsection III.B has introduced the notion of pluggable CATs. Their adaptation capabilities are described in *CAT Capabilities DIs* (also introduced in Subsection III.B). One CAT can be used as soon as this CAT and its corresponding *CAT Capabilities DI* are plugged in CAIN-21.

1) CAT Capabilities and Conversion Capabilities

The notion of *CAT Capabilities* was introduced in [28]. The following paragraphs describe the current *CAT Capabilities* description tool of CAIN-21 and compare it with the standard *ConversionLink* [9].

Subsection II.B explained that MPEG-21 Part 7 Amendment 1 defines a *conversion* as an (software or hardware) element capable of performing multimedia adaptation. The original *CAT Capabilities* only allowed describing one conversion. The final *CAT Capabilities* can incorporate several conversion elements. During the development of CAIN-21, we observed the practical fact that conversion capabilities are not always easy to describe with only one conversion. With some types of adaptations, we need to divide the capabilities of an individual *CAT Capabilities* element into several *Conversion Capabilities* elements. Consider, for example, a CAT that is capable of accepting JPEG and PNG images, but PNG images are accepted only in greyscale, whereas JPEG images are accepted in both colour and greyscale. In this case, the *CAT Capabilities DI* must be split into two separate *Conversion Capabilities*. The first *Conversion Capabilities* element states that PNG images are accepted in greyscale. The second *Conversion Capabilities* element states that JPEG images are accepted in both colour and greyscale.

The second major feature implies the description of the values that properties can take. In the CAIN-21 decision process, preconditions, postconditions and parameters can take several possible values (e.g. *format* = {*mpeg*-1, *mpeg*-2, *mpeg*-4}). We have modified the description of the conversions so that each input and output property can take multiple values.

```
<dia:DIA xmlns="urn:vpu:cain21-cat-capabilities"
         xmlns:dia="urn:mpeg:mpeg21:2003:01-DIA-
NS"
         xmlns:mpeg7="urn:mpeg:mpeg7:schema:2001"

xmlns:xsi="http://www.w3.org/2001/XMLSchema-
instance">
 <dia:Description xsi:type="CATCapabilitiesType"
id="video_transcoder_cat">

<CATClassName>es.vpu.cain21.cats.VideoTranscoderCA
T</CATClassName>
   <Platform>
    <ValueSet>
     <Value href="Windows XP">Windows</Value>
     <Value href="Linux">Linux</Value>
     <Value href="Mac OS X">Mac OS X</Value>
    </ValueSet>
    </Platform>
    <!-- Online MPEG conversion using the ffmpeg
library -->
   <ConversionCapability
xsi:type="ConversionCapabilityType"

id="online_mpeg_transcoder">
     <ContentDegradation>0</ContentDegradation>
     <ComputationalCost>1.0</ComputationalCost>
     <Preconditions>
      <URL>
       <AnyValue/>
      </URL>
      <Binding>
       <ValueSet>
        <Value href="urn:mpeg:mpeg21:2007:01-BBL-
NS:handler:HTTP">HTTP</Value>
        <Value href="urn:mpeg:mpeg21:2007:01-BBL-
NS:handler:FILE">FILE</Value>
       </ValueSet>
      </Binding>
      <Content>
       <ValueSet>
        <Value
href="urn:mpeg:mpeg7:cs:ContentCS:2001:2">Audiovis
ual</Value>
        <Value
href="urn:mpeg:mpeg7:cs:ContentCS:2001:4.2">Video<
/Value>
       </ValueSet>
      </Content>
      <FileFormat>
       .............
      </FileFormat>
      <Bitrate>
       <RangeValueSet from="5000" to="1000000"/>
      </Bitrate>
      ...............
     </Preconditions>
     <Postconditions>
      .................
     </Postconditions>
   </ConversionCapability>
   <!-- On Demand MP4 conversion using the ffmpeg
command -->
   <ConversionCapability
xsi:type="ConversionCapabilityType"

id="ondemand_mp4_transcoder">
     ..................
     ..................
  </ConversionCapability>
 </dia:Description>
</dia:DIA>
```

Listing 1: CAT Capabilities DI example

The XML Schema of the *CAT Capabilities* description tool that we propose is available in the file *ccatc.xsd* of the CAIN-21 software. The *CATCapabilitiesType* represents a CAT. The *ConversionCapabilitiesType* represents each conversion that the CAT is capable of performing. Listing 1 shows a fragment of one of the *CAT Capabilities DIs* fully available in the CAIN-21 demo. The CAT comprises two *ConversionCapability* elements named *online_mpeg_transcoder* and *ondemand_mp4_transcoder*. The *Preconditions* and *Postconditions* elements contain information related to the media format that each conversion accepts and produces. These properties are inspired by MPEG-7 Part 5. Note that the properties can be single-valued or multi-valued by means of the *ValueSet* element. The *RangeValueSet* element enables the description of ranges. The *AnyValue* element represents a placeholder whenever the value of the parameter must be provided, but every value is acceptable.

2) Comparison with the ConversionLink

Subsection II.B describes that MPEG-21 Part 7 Amendment 1 has standardised the *ConversionLink* description tool. This tool provides a means for linking steering description parameters and conversion capabilities description. *ConversionLink* uses the *ConversionCapability* element to describe the adaptation capabilities.

The *CATCapabilitiesType* of CAIN-21 is defined as a derivation by restriction of the *DIADescriptionType* of MPEG-21. Therefore, the *CATCapabilitiesType* can be seen as a (non-MPEG-21 standardised) *DIA* description tool.

More specifically, the *ConversionCapabilityType* of MPEG-21 is a generic container that used the following type to enable any description:

```
<any namespace="##other" processContents="lax" minOccurs="0"/>
```

The *ConversionCapabilityType* of CAIN-21 is defined as a derivation by extension of this *ConversionCapabilityType*. Therefore, the *ConversionCapabilityType* of CAIN-21 can be seen as an instance of the generic *ConversionCapabilityType* that MPEG-21 provides. In particular, CAIN-21 describes the conversions by means of preconditions and postconditions. This description model suits the automatic decision mechanism of CAIN-21.

Authors such as [10] also use the *ConversionCapability* element[6] together with the *ConversionLink*. In this case, the author makes use of RDF tuples to describe the adaptation capabilities and its semantics. CAIN-21 instead uses preconditions and postconditions that best suit its decision-making mechanism.

D. Binding modes

Subsection II.E explained the Offline/On-demand/Online adaptation modes. CAIN-21 supports all these modes. Subsection II.E has highlighted the difference between adaptation and delivery. Although CAIN-21 is focused on adaptation, delivery is supported to a certain extend. *Binding modes* have been introduced in CAIN-21 to support media delivery. In particular, delivery can be envisioned as a type of adaptation. The binding modes indicate the delivery mechanism that the conversion uses to receive and transmit the media (such as *FILE*, *HTTP* or *RSTP*). This work proposes to use the *mpeg21:Handler* description tool of the *Bitstream Binding Language* (BBL) [30]. The binding modes are used with two purposes: (1) to transfer the media between CATs in a sequence of CATs and (2) to transfer the media from the last CAT in the sequence to the consumption terminal. **TABLE** shows the binding modes currently available in CAIN-21. The *INPROCESS* binding mode allows efficient transfer of the media resource between CATs.

[6] The author uses the name *ConversionDescription* to refer to the notion of *ConversionCapability*.

In CAIN-21 each *ConversionCapabilities* element must provide in its preconditions and postconditions the available *binding modes*. For instance, in Listing 1, the first *ConversionCapabilities* element supports *FILE* and *HTTP* in its preconditions (i.e. in the input of the corresponding conversion). The *Terminal* element of the *Usage Environment DI* must also indicate the delivery modes that it supports to receive media. Listing 3 below shows how the binding modes of a terminal are provided into its terminal description. Listing 1 and Listing 3 show that the binding mode, of both the *online_mpeg_transcoder* and the terminal, can take more that one value. In these examples, both the conversion described in Listing 1 and the terminal described in Listing 3 support the *FILE* and *HTTP* binding modes.

The current release of CAIN-21 includes one CAT (named *HttpVideoStreamingCAT*), which only purpose is to provide HTTP video delivery. If necessary, the decision mechanism automatically adds this CAT to the sequence of CATs. Specifically, this CAT is added at the end of the sequence when the last CAT of the sequence does not provide *HTTP* binding mode in its postconditions (for instance, because the CAT only provides *FILE* binding mode in its postconditions) and the terminal binding mode is defined as *HTTP* only capable.

TABLE I
BINDING MODES PROPOSED BY CAIN-21

Binding mode	**Description**
urn:mpeg:mpeg21:2007:01-BBL-NS:handler:INPROCESS	In-process technique used to transfer information between CATs. In the case of CAIN-21, objects loaded in memory use the pull model to request data by means of a memory buffer.
urn:mpeg:mpeg21:2007:01-BBL-NS:handler:FILE	Can read/write files provided in the URL. This is an appropriate binding for OdA mode
urn:mpeg:mpeg21:2007:01-BBL-NS:handler:TCP	Can read/write TCP sockets. The IP+port are provided in the URL. This is an appropriate binding for OnA mode.
urn:mpeg:mpeg21:2007:01-BBL-NS:handler:HTTP	Can read/write HTTP protocol. The IP+port are provided in the URL. This is an appropriate binding for OnA mode.
urn:mpeg:mpeg21:2007:01-BBL-NS:handler:RTSP	Can read/write RTSP protocol. The IP+port are provided in the URL. This is an appropriate binding for OnA mode.

E. Properties DI

The *Properties DI* tool gathers all the information required by the multimedia adaptation process following a declarative approach. The main purpose of this tool is that changes in the set of multimedia properties do not imply changes in the underlying source code. Particularly, with the *Properties DI* tool all the information is described consistently using so called *multimedia properties*. These multimedia properties include the *Content DI*, the *Usage Environment DI* and the *CAT Capabilities DI*. Each property is represented as a label with an associated XPath [8] expression.

1) Addressing mechanism

Even though the PM is still responsible for parsing the documents and loading them in memory, the ADM does not directly access these properties. In this way, changes in the metadata do not imply changes in the underlying source code. Instead, these changes imply only modifying the *Properties DI*.

```
<dia:DIA xmlns="urn:vpu:cain21-properties-di"
         xmlns:dia="urn:mpeg:mpeg21:2003:01-DIA-
NS"
         xmlns:mpeg7="urn:mpeg:mpeg7:schema:2001"

xmlns:xsi="http://www.w3.org/2001/XMLSchema-
instance">
 <dia:Description xsi:type="PropertiesDIType">
  <DIProperties>
    <Property name="genre" required="false"

xpath="/Item/Descriptor/Statement/Mpeg7/Descriptio
nUnit/Genre/@href"/>
  </DIProperties>
  <ComponentProperties>
   <Property name="id" required="true"
xpath="/@id"/>
   <Property name="url" required="true"
xpath="/Resource/@ref"/>
   <Property name="mime_type" required="false"
xpath="/Resource/@mimeType"/>
    ..................
   <ComposedProperty name="visual_frame"
required="false">
    <Value
xpath="//Mpeg7/Description/MediaInformation/MediaP
rofile

//MediaFormat/VisualCoding/Frame/@width"/>
    <Value
xpath="//Mpeg7/Description/MediaInformation/MediaP
rofile

//MediaFormat/VisualCoding/Frame/@height"/>
   </ComposedProperty>
  </ComponentProperties>
  <CATProperties>
   <Property name="id" required="true"
xpath="/@id"/>
   <Property name="cat_class_name" required="true"
xpath="/CATClassName"/>
   ....................
  </CATProperties>
  <ConversionProperties>
   <Property name="id" required="true"
xpath="/@id"/>
   <Property name="content_degradation"
required="true"
             xpath="/ContentDegradation"/>
   <Property name="computational_cost"
required="true"
             xpath="/ComputationalCost"/>
   <!-- Input properties -->
   <Property name="pre_url" required="true"
xpath="/Preconditions/URL"/>
   <Property name="pre_binding" required="true"
xpath="/Preconditions/Binding"/>
   <Property name="pre_content" required="true"
xpath="/Preconditions/Content"/>
    ..............
   <!-- Output properties -->
   <Property name="post_url" required="true"
xpath="/Postconditions/URL"/>
   <Property name="post_binding" required="true"
xpath="/Postconditions/Binding"/>
   <Property name="post_content" required="true"
xpath="/Postconditions/Content"/>
    .................
  </ConversionProperties>
  <UsageEnvProperties>
   <TerminalProperties>
    <Property name="id" required="true"
xpath="/@id"/>
    <Property name="binding" required="true"

xpath="/TerminalCapability[@type='cde:HandlerCapab
ilitiesType']
          /Handler/@handlerURI"/>
     ..........
   </TerminalProperties>
   <NetworkProperties>
    <Property name="id" required="true"
xpath="/@id"/>
    <Property name="max_capacity" required="false"

xpath="/NetworkCharacteristic/@maxCapacity"/>
    <Property name="min_guaranteed"
required="false"

xpath="/NetworkCharacteristic/@minGuaranteed"/>
   </NetworkProperties>
   <UserProperties>
    <Property name="id" required="true"
xpath="/@id"/>
     ..............
    <Property name="pref_focus_of_attention"
required="false"

xpath="/UserCharacteristic/ROI/@uri"/>
   </UserProperties>
  </UsageEnvProperties>
 </dia:Description>
</dia:DIA>
```

Listing 2: Properties DI example

The expression of each property points out to the part of the DI where its values are located. XPath expressions are relative to the document. Therefore, the *Properties DI* stores only the XPath of the property. The document that contains these properties is determined during the execution of the adaptation. The *Configuration DI* (introduced in Subsection IV.A) is used to identify these documents. Furthermore, properties are only resolved on-demand. In this way, properties that are never used are not extracted from de DIs. Internally, CAIN-21 uses *xpointer*() [24] expressions to reference both the document and the XML element or attribute to be accessed. The standard Xalan processor [31] is used in our work to gather all these properties.

The *Properties DI* schema that we propose is available in the file *cpr.xsd* of the CAIN-21 software. The *PropertiesDIType* is defined as a derivation by restriction of the MPEG-21 standard *DIADescriptionType*. This type includes four important elements that correspond to the five groups of properties: *DIProperties*, *ComponentProperties*, *CATProperties*, *ConversionProperties* and *UsageEnvProperties*. Listing 2 shows the more relevant parts of the current *Properties DI* of CAIN-21 (the whole document is available in the file *pr.xml* of the CAIN-21 demo). For instance, in Listing 2 the *ConversionProperties* element contains the property *pre_url* whose XPath expression is

"*/Preconditions/URL*". On resolving this XPath expression in Listing 1, *AnyValue* is obtained indicating that the conversion accepts any value for this property. As another example, on resolving the *pre_binding* property in Listing 2, the *FILE* and *HTTP* binding modes are obtained from Listing 1.

2) Properties and relationships

Subsection IIII.A introduced the Semantic Web. Semantic Web languages such as OWL allow explicitly representing and storing concepts and their relationships in a semantic graph. Software tools such as Protégé facilitate loading this graph from disk to memory. Frequently, automatic-reasoning techniques use this graph to search for relationships among the values and to infer additional information.

In CAIN-21, the concepts are represented by means of properties and the relationships are limited. Specifically, relationships are just intended to assist the matching algorithm developed in [17]. In this way, CAIN-21 uses a delimited subset of the rich relationships that the Semantic Web provides.

The *Properties DI* complies with the *Keep It Short and Simple* (KISS) design principle. This principle recommends to avoid unnecessary complexity and construct systems as simple as possible, but no simpler. The main purpose of the *Properties DI* is not information inference, but to elude changes in the decision algorithm when the metadata under consideration evolves. In contrast, depending on the reasoning techniques, changes in the relationships of the semantic graph imply changes in the underlying reasoning algorithms.

In a nutshell, the matching mechanism tests whether the input of one CAT accepts the output of the previous CAT in the sequence. The matching mechanism also tests whether the terminal accepts the output of the last CAT. In order to perform these tests, usually the simple properties-based representation mechanism has demonstrated to be enough [17]. These tests demonstrated its suitability and also demonstrated that the matching mechanism operates efficiently. However, during the tests, we encountered that occasionally it is convenient to consider more complicated relationships between properties. For instance, to maintain the ratio in the adapted media the width and height should be considered together. In these cases, we use *composed properties*. Listing 2 shows an example of these composed properties. The *visual_frame* property uses the *ComposedProperty* element to gather the width and height elemental values. In the representation schema of CAIN-21, these elemental values can be represented by means of ranges or as a placeholder accepting any value.

F. Extensions to the UED

In particular, this document has identified the following handicaps in the current UED:

1. The *mpeg21:TerminalType* does not include any reference to the modalities of the content that the terminal consumes (images, video, audiovisual, audio, etc). The *mpeg7:Content* description serves this purpose by the *mpeg7:ContentCS* classification scheme

2. The terminal does not provide any description of the binding modes, i.e., the delivery mechanism (such as *HTTP* or *RTSP*) used to consume content as described in Subsection IV.D.

3. The standard MPEG-21 Part 7 *UED* tools do not specify whether the properties of the terminal are mandatory or optional. For instance, if the terminal is defined using the *mpeg21:AudioCapabilitiesType*, does it mean that the adapted media must include audio? Or does it mean that this audio format could be consumed if present?

These semantic gaps include both properties that can be inferred and properties that cannot be inferred (ambiguities). The first gap semantic can be addressed by inference [32] and the other two gaps by extending the current *mpeg21:TerminalType*. More specifically, the first gap can be addressed by inferring the media content (image, video, audiovisual, audio) from the *mpeg21:TransportCapabilitiesType* (illustrated in Listing 3).

To demonstrate how to address the other two gaps, Listing 3 shows a portion of the description of the terminal with *id="iphone"* from the CAIN-21 demo. The extensions that this subsection discussed are marked in bold. The XML Schema with these changes is publicly available in the file *cde.xsd* of the CAIN-21 software.

```
<Terminal id="iphone" xsi:type="cde:TerminalType">
 <TerminalCapability
xsi:type="cde:HandlerCapabilitiesType">
  <Handler handlerURI="urn:mpeg:mpeg21:2007:01-
BBL-NS:handler:FILE"/>
  <Handler handlerURI="urn:mpeg:mpeg21:2007:01-
BBL-NS:handler:HTTP"/>
 </TerminalCapability>
 <TerminalCapability
xsi:type="cde:CodecCapabilitiesType">
  <cde:Decoding
xsi:type="cde:TransportCapabilitiesType">
   <cde:Format
href="urn:vpu:cs:FileFormatCS:2009:3gpp">
    <mpeg7:Name xml:lang="en">
     3GPP file format
    </mpeg7:Name>
   </cde:Format>
  </cde:Decoding>
  <cde:Decoding
xsi:type="cde:VideoCapabilitiesType">
   <cde:Format
href="urn:vpu:cs:VisualCodingFormatCS:2007:1">
    <mpeg7:Name xml:lang="en">
     H.264 Baseline Profile @ Level 1.1
    </mpeg7:Name>
   </cde:Format>
   <cde:CodecParameter
xsi:type="CodecParameterBitRateType">
    <BitRate >32000</BitRate>
   </cde:CodecParameter>
  </cde:Decoding>
  <cde:Decoding
xsi:type="cde:AudioCapabilitiesType"
optional="true">
   <cde:Format
href="urn:mpeg:mpeg7:cs:AudioCodingFormatCS:2001:4
.3.1">
    <mpeg7:Name xml:lang="en">
     MPEG-2 Audio AAC Low Complexity Profile
    </mpeg7:Name>
   </cde:Format>
   <cde:CodecParameter
xsi:type="CodecParameterBitRateType">
```

```
      <BitRate>7950</BitRate>
     </cde:CodecParameter>
    </cde:Decoding>
   </TerminalCapability>
    ....................
  </Terminal>
```

Listing 3: Extended mpeg21:TerminalType

The proposed extensions to the *mpeg21:TerminalType* are:

1. Representing the binding modes of the terminal in the *cde:HandlerCapabilitiesType* description tool. This element makes reference to the *mpeg21:Handler* description tool. shows how to describe that the iPhone terminal supports the *FILE* and *HTTP* binding modes.

2. Mandatory and optional constrains are instances of the hard and soft constraints model developed in [17]. To provide this description, CAIN-21 extends the *mpeg21:TerminalType* with the *optional* attribute. Listing 3 shows how to signal that the audio stream is optional using the optional attribute in the *cde:AudioCapabilitiesType*. If this attribute is absent, CAIN-21 considers the terminal description as a mandatory constraint.

V. TESTS AND VALIDATION

The CAIN-21 demo, publicly available at *http://cain21.sourceforge.net*, provides several tests demonstrating the multimedia adaptation approach of this paper. This section focuses on demonstrating and validating the extensions to the MPEG-21 standard proposed in Section IV.

Subsection III.A described the DI level adaptation interface. Both operations of this interface – i.e., *transform*() and *addVariation*() – have been used in the tests. In addition, to cover a wide range of multimedia adaptations, both images and videos have been selected for the tests reported in this paper. CAIN-21 can also convert images to video through the *Image2VideoCAT*. Its *image_2_video* conversion has also been covered in the tests.

A. Transforming an image to an small video terminal

Test 1 illustrates how a *Content DI* with an image (named *photo.xml*) is adapted to the *id="iphone"* video terminal (shown in Listing 3). The full description of these elements is available in the CAIN-21 demo. The *transform*() software interface receives a *Configuration DI* (described in Subsection IV.A) to indicate the target terminal. The PM of CAIN-21 (described in Subsection III.B) uses the *Properties DI* to gather the properties of the *Content DI*, *CAT Capabilities DIs* and *Usage Environment DI*. After that, the ADM (introduced in Subsection III.B) produces the following sequence of conversions *initial* → *image_transcoder* → *image_2_video* → *ondemand_video_transcoder* → *goal*. In this sequence, *initial* represents the properties of the original *Content DI*. The *Preconditions* and *Postconditions* of *image_transcoder*, *image_2_video* and *ondemand_video_transcoder* are described in their corresponding *ConversionCapabilities* elements as explained in Subsection IV.C. Lastly, *goal* represents the properties adapted content. The *image_transcoder* conversion transcodes the image format and size to the preconditions of the *image_2_video* conversion (i.e., JPEG image format and 3:4 aspect ratio). The *image_2_video* conversion accepts only JPEG images and produces only MPEG-2 video. *The ondemand_video_transcoder* (whose conversion capabilities appear in Listing 1) transcodes the MPEG-2 video to the constraints of the terminal (3GPP according to Listing 3). In this Test 1, the ADM has selected the *FILE* binding mode the conversions steps. This happened because all the conversions provide this transfer mechanism in their *Preconditions* and *Postconditions* description tools.

If we change the terminal of Test 1 from *"iphone"* to *"http_nokia_n95"*, we have the didactic Test 2. This test fully demonstrates the usefulness of the binding modes. In Test 2, CAIN-21 produces a sequence with four conversions *initial* → *image_transcoder* → *image_2_video* → *ondemand_video_transdoder* → *http_delivering* → *goal*. Specifically, CAIN-21 has added to the end of the sequence the *http_delivering* conversion to change the binding property from *FILE* to *HTTP*. In Test 1 the *"iphone"* terminal supported the *FILE* delivery mechanism (see Listing 3), which corresponds to the binding property at the output of *ondemand_video_transcoder*. Therefore CAIN-21 did not add the *http_deliveding* conversion at the end of the sequence. However, in Test 2, the *"http_nokia_n95"* terminal only supports the *HTTP* binding mode, and therefore CAIN-21 has added the *http_delivering* conversion at the end of the sequence. This conversion has the *FILE* binding mode in its preconditions and the *HTTP* binding mode in its postconditions: this indicates that the purpose of this tool is to transfer the input file using the *HTTP* standard protocol.

B. Summarizing variations of video news items

Test 3 summarizes and adapts a *Content DI* containing a news item to three different terminals [33]. Listing 4 shows the original *Content DI* to be adapted.

```
<DIDL xmlns="urn:mpeg:mpeg21:2002:02-DIDL-NS"
      xmlns:xsi="http://www.w3.org/2001/XMLSchema-
instance"
      xmlns:cdi="urn:vpu:cain21-di"
      >
 <Item xsi:type="cdi:ItemType">

  <!-- Classification -->
  <Descriptor>
   <Statement mimeType="text/xml">
    <Mpeg7 xmlns="urn:mpeg:mpeg7:schema:2004">
     <DescriptionUnit xsi:type="ClassificationType">
      <Genre
href="urn:mpeg:mpeg7:cs:ContentCS:2001:1.1.13">
       <Name xml:lang="en">Natural disasters</Name>
      </Genre>
      <Genre
href="urn:mpeg:mpeg7:cs:ContentCS:2001:1.5.1">
       <Name xml:lang="en">Political</Name>
      </Genre>
     </DescriptionUnit>
    </Mpeg7>
   </Statement>
  </Descriptor>
  <!-- Original content -->
```

```
  <Component xsi:type="cdi:VideoComponentType"
id="original">
   <Descriptor xsi:type="cdi:Mpeg7DescriptorType">
    <!-- MPEG-7 MediaDescriptionType describing the
resource -->
    ................
   </Description>
   <Resource mimeType="video/mpeg"
ref="../mesh/didl/flood2video.mpg"/>
  </Component>
 </Item>
</DIDL>
```

Listing 4: Original DI to be summarized and adapted in Test 3

The MPEG-7 *ClassificationType* description type indicates that the news item contains natural disaster and political content. The video is stored in a *Component* element with *id="original"*. This *Component* contains and MPEG-7 *MediaDescriptionType* description of the *Resource* element. The original video is MPEG-1 video and has a resolution of 720x576. This video is summarized according to the methods explained in [33]. Subsequently, the DI is adapted to three terminals. The terminals for the adaptation are all MPEG-2 terminals and have, respectively, screen sizes of 720x576, 352x288 and 176x144. In Test 2, the *addVariation*() operation is used to create the adapted videos in additional *Component* elements of the *Content DI*. Listing 5 shows the adapted *Content DI* with four *Component* elements: the original video and three summarized and adapted variations. The MPEG-7 *VariationDescriptionType* description type indicates that the original video (with *id="original"*) has three variations in the *Component* elements with IDs *"big-sum"*, *"medium-sum"* and *"small-sum"*.

```
<DIDL xmlns="urn:mpeg:mpeg21:2002:02-DIDL-NS"
      xmlns:xsi="http://www.w3.org/2001/XMLSchema-
instance"
      xmlns:cdi="urn:vpu:cain21-di"
      xmlns:mpeg7="urn:mpeg:mpeg7:schema:2004">
 <Item xsi:type="cdi:ItemType">
  <!-- Classification -->
  .......................
  <!-- Original content -->
  <Component xsi:type="cdi:VideoComponentType"
id="original">
   ..........
   <Descriptor xsi:type="VariationDescriptionType">
    <VariationSet>
     <Source xsi:type="AudioVisualType">
      <AudioVisual>
       <MediaLocator>
        <MediaUri>#original</MediaUri>
       </MediaLocator>
      </AudioVisual>
     </Source>
     <Variation priority="1">
      <Content xsi:type="AudioVisualType">
       <AudioVisual>
        <MediaLocator>
         <MediaUri>#big-sum</MediaUri>
        </MediaLocator>
       </AudioVisual>
      </Content>
      <VariationRelationship>
       summarization
      </VariationRelationship>
     </Variation>
     <Variation priority="2">
      <Content xsi:type="AudioVisualType">
       <AudioVisual>
        <MediaLocator>
         <MediaUri>#medium-sum</MediaUri>
        </MediaLocator>
       </AudioVisual>
      </Content>
      <VariationRelationship>
       summarization
      </VariationRelationship>
     </Variation>
     <Variation priority="3">
      <Content xsi:type="AudioVisualType">
       <AudioVisual>
        <MediaLocator>
         <MediaUri>#small-sum</MediaUri>
        </MediaLocator>
       </AudioVisual>
      </Content>
      <VariationRelationship>
       summarization
      </VariationRelationship>
     </Variation>
    </VariationSet>
   </Descriptor>
   ...............
   <Resource mimeType="video/mpeg"
ref="../mesh/didl/flood2video.mpg"/>
  </Component>
  <!-- Big size summarized content -->
  <Component xsi:type="cdi:VideoComponentType"
id="big-sum">
   .................
  </Component>
  <!-- Medium size summarized content -->
  <Component
xsi:type="cdi:VideoComponentType"id="medium-sum">
  </Component>
  <!-- Small size summarized content -->
  <Component xsi:type="cdi:VideoComponentType"
id="small-sum">
   ...........
</Component>
 </Item>
</DIDL>
```

Listing 5: Summarized and adapted DI in Test 3

Test 3 uses three *Configuration DIs*. These *Configuration DIs* use the *ARC* descriptions (described in Subsection IV.B) to request the adaptation to three terminals respectively labelled as *"720x576"*, *"352x288"* and *"176x144"* in the *Usage Environment DI*. For Test 3, we needed to create a CAT named *RawVideoCombinerCAT*. Its *CAT Capabilities* appear in the file *raw_video_combiner_cat.xml* of the CAIN-21 demo. This CAT was necessary to retrieve the summarized video from the summarization module (further explained in [33]) through two TCP sockets: one for raw WAV audio and one for RAW video. To this end, we created an additional binding mode (see Subsection IV.D) labelled as *urn:mpeg:mpeg21:2007:01-BBL-NS:handler:TCP*.The three terminals in Test 3 were defined with the standard *HTTP* binding mode in TABLE . During the adaptation, the ADM produced a sequence with three conversions: *initial* → *raw_video_combiner* → *online_video_transcoder* → *http_delivering* → *goal*.

C. Extensions demonstrated in the tests

To recapitulate, justify and validate the extensions to the MPEG-21 schema that this paper proposes the following conclusions are offered:

1. The proposes description schema enables the description of multiple terminals respectively labelled in the tests of this section as *"iphone"*, *"http_nokia_n95"*, *"720x576"*, *"352x288"* and *"176x144"*. To indicate the target terminal of the adaptation this information has to be provided. As MPEG-21 does not define a description tool for this purpose, Subsection IV.B has proposed this description tool.

2. To enable automatic adaptation decision, the inputs and outputs of the conversion tools have to be provided. Subsection IV.C proposed the *CAT Capabilities* description tools. The feasible inputs and output properties are defined using the *Preconditions* and *Postconditions* elements.

3. For automatic decision, it is also necessary to know how the media is going to be transferred to both the next CAT and the target terminal. This justifies the introduction of the binding mode in the description schema.

4. The modality of the content appears in the *mpeg7:Content* description tool. However, this information is not provided by the *mpeg21:TerminalType* description type. During the decision process the modality of the content that the terminal accepts has to be determined. The inference rule described in Subsection IV.F can be used in this case. Specifically, from the *mpeg21:TransportCapabilitiesType* description tool of Listing 3 it can be inferred that the content has to be visual or audiovisual. See [32] for a further explanation of this mechanism.

5. In Test 2 the decision process needs to know the binding mode to identify that the *http_delivering* conversion has to be added to the sequence. This information removes ambiguity and validates the first extension in Subsection IV.F.

6. Before adding the *optional* attribute to the *mpeg21:AudioCapabilitiesType* description (extension 2 in Subsection IV.F), CAIN-21 did not encounter a sequence for Test 1 and Test 2. This happened because the output of the *image_2_video* conversion did not contain this information. This problem has been further described in [32]. Labelling the audio as *optional* (see Listing 3) allows for ignoring the audio properties during the computation of the sequence.

VI. Multimedia Adaptation Engines Comparison

This section provides a comparative review of six multimedia adaptation engines, which operate in the MPEG-21 framework: ConversionLink [10], koMMa [15], BSD [12], DCAF [20] NinSuna [21] and CAIN-21. These engines have been introduced in Subsection II.D. **Table** shows the year of publication that this paper is analyzing.

A. Aspects to compare

The comparison based on six aspects, namely:

1. The automatic *decision-making method* that the engine implements.

2. Whether the engine supports *multi-step* adaptation.

3. Whether the engine provides a *complete-solution*, i.e., finds all the solutions.

4. The *extensibility mechanism* (if any).

5. The *multimedia content* that the engine is prepared to adapt.

6. The *semantic adaptations* that the engine considers.

TABLE II
SUMMARY OF COMPARATIVE OF MULTIMEDIA ADAPTATION ENGINES

	ConversionLink	koMMa	BSD	DCAF	NinSuna	CAIN-21
Year	2005	2007	2008	2008	2010	2013
Decision-making method	Ad-hoc	Knowledge-based	Quality-based	Quality-based	Quality-based	Knowledge-based + Quality-based
Multi-step	No	Yes	Yes	No	No	Yes
Complete solutions	Unspecified	No	Ranking	Ranking	Unspecified	Knowledge-based + Ranking
Extensibility mechanism	Yes	Yes	No	No	Yes	Yes
Multimedia content	Images + Video + Audio	Image + Video	Scalable content	General video	Scalable content	Images + Video + Audio
Semantic adaptation	Scene adaptation	OWL description	gBSD + IOPins	gBSD + IOPins	RDF + gBSD + SOIs	ROI

Subsection II.C divided automatic decision-making methods into quality-based methods and knowledge-based methods. koMMa and CAIN-21 rely on knowledge-based methods, whereas BSD, DCAF and NinSuna rely on quality-based methods. ConversionLink is a generic description engine that does not specify the algorithms used to make the adaptation decisions. BSD and DCAF engines use the notion of Pareto optimality. CAIN-21 also uses quality-based decisions during a second step (see, [18] for a further discussion on how CAIN-21 implements these quality-based decisions). Whereas BSD, Ninsuna and CAIN-21 rely on classical multi-attribute optimisation methods, DCAF exploits genetic algorithms to compute this optimization.

Section I introduced the advantages that multi-step adaptation provides. These advantages are frequently studied in knowledge-based methods. The koMMa and CAIN-21 adaptation engines use these methods. BSD is mainly devoted to performing the adaptation of the scalable resource in one step. Nonetheless, the authors have also studied the problem of distributed adaptation, which corresponds to the idea of multistep adaptation in different nodes.

In reference to completeness, quality-based methods usually obtain a complete solution, i.e., all the feasible solutions are obtained and ranked: this is the case of BSD, DCAF and CAIN-21. More specifically, these engines create a ranking among the available solutions. Well-known quality metrics such as PSNR or VQM [34] are used to create this ranking. Regarding the knowledge-based methods, koMMa only extracts one solution. CAIN-21 analyses all of them using both the knowledge-based and quality-based decision methods. NinSuna and ConversionLink do not specify the completeness of their decisions.

The idea of extensibility appears in ConversionLink, koMMa, NinSuna and CAIN-21. Both the *ConversionLink* and the *CATCapabilities* description tools include the standard *ConversionCapabilities* [9] description tool. The differences between these descriptions were discussed in Subsection IV.C. BSD and DCAF do not examine their own extensibility.

NinSuna discusses its extensibility regarding its format independence.

In reference to the supported media, BSD and NinSuna are particularly effective dealing with scalable media, while DCAF deals with general video resources. ConversionLink, koMMa and CAIN-21 are intended to deal with a wider range of media resources. Specifically, ConversionLink and CAIN-21 can manage images, audio and video, whereas koMMa provides adaptation tests involving images and video. The scalable content adaptation implemented in BSD and DCAF is one of the adaptations that CAIN-21 incorporates. Moreover, [18] discusses how scalable video adaptation is carried out inside a CAT called the SVCCAT. The scalable content adaptation corresponds to to the idea of resource conversion in the case of ConversionLink.

In reference to semantic adaptations, *ConversionLink* allows scene level adaptation. It addresses the question of semantic adaptation of documents based on temporal, spatial and semantic relationships between the media objects. koMMa relies on Semantic web Services to describe its adaptation capabilities and to identify the sequence of conversions. BSD and DCAF use the *gBSD* [3] and the *AdaptationQoS* with *IOPins* [3] description tools. *IOPins* are linked to semantics annotating the video stream on a semantic level. NinSuna uses RDF to describe semantic relationships. It also uses the *gBSD* description tools to provide semantic adaptation for the selection of *Scenes Of Interest* (SOIs) as well as for frame-rate reduction. CAIN-21 makes use of *Regions of Interest* (ROIs) inside some CATs such as the *Image2VideoCAT*. Tests involving semantic adaptation in CAIN-21 have been reported to [19].

B. Adaptation approaches comparison

This section describes the reasoning behind the different approaches chosen for the adaptations engines described above.

In the design of ConversionLink it can be observed an effort to create a general MPEG-21 description of multimedia adaptation, but without paying attention to the underlying adaptation algorithms. Several adaptations are described, but they are ad-hoc adaptations of a specific media item, that is, the decision and adaptation methods do not generalize to make them reusable for other media contents or formats without modifying the underlying implementation.

The major contribution of koMMa is to demonstrate how Web Services are able to represent and calculate multimedia adaptation sequences. koMMa studies in depth the semantic description and planning of the sequence, but defers the study and exploitation of the signal level features of the media to be adapted.

The reasoning behind quality-based methods (i.e., BSD, DCAF and NinSuma) is to find the parameters that maximize the quality or utility of the adaptation. These parameters exist or are applicable only to specific media formats (e.g., scalable video), and hence these methods do not aim to accomplish the adaptation of the widest possible range of multimedia formats. Conversely, knowledge-based methods (such as koMMa or the first phase of CAIN-21) focus on the reusability of the adaptation algorithms as a mean to archive the widest possible range of adaptations. With this purpose, knowledge-based methods propose the use of pluggable adaptation tools, and elaborate a decision method that, without human intervention, finds the adaptation tools and corresponding parameters to accomplish each adaptation scenario.

CAIN-21 contributes to the previous ideas by proposing the combination of knowledge-based and quality-based methods in two steps. Firstly, a descriptions-based method that finds all the feasible adaptations, secondly the CATs use media features to select the parameters that maximize the quality or utility of the adaptation.

VII. Contributions and conclusions

The objective of the Semantic Web is to represent knowledge in a format that can be automatically processed without human intervention. This paper contributes to this objective by introducing the idea of implied and explicit ontology, envisioning MPEG-21 as a implied ontology, and demonstrating how this (pseudo)-ontology is enough to accomplish multimedia adaptation decision-making automatically (i.e., without human intervention in the decision process).

This paper has explained CAIN-21, its extensibility mechanism and the infrastructure to perform automatic adaptation decisions. So, assuming that enough CATs are available, CAIN-21 is capable of managing all content that can be represented as a DI.

As said, CAIN-21 embraces MPEG-21 and shows its good level of expressiveness, as most of new descriptions for concepts and relationships can be represented with this standard. However, this paper has identified and discussed several handicaps in the MPEG-21 description capabilities. As discussed in Section 4, extensions were provided to solve these handicaps. In particular, the paper identifies gaps in the MPEG-21 schema to represent the UED, in the binding modes, in the *ConversionCapabilities* to represent preconditions and postconditions, and in the *mpeg7:Content* description tool.

Another important unique aspect of CAIN-21 is that semantic and quality-based adaptations have been put apart from the knowledge-based decision mechanism and transferred to the CATs. Therefore, our proposal for the knowledge-based decision method makes the adaptation engine independent of the semantics in the content to be adapted. Specifically, the independence is achieved by making decisions according to the media format. Subsequently, quality-based and semantic adaptation for particular content (e.g. soccer, news items) can be integrated inside the CATs. As can be seen in Table , CAIN-21 combines these two major decision-making methods and integrates a complete algorithm, i.e., an algorithm that identifies all the feasible adaptations that produce content satisfying the usage environment constraints.

The paper also includes the reasoning behind and comparison of the different multimedia adaptation decision approaches.

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An Agent-Based Approach for Evaluating Basic Design Options of Management Accounting Systems

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***Abstract* — This paper investigates the effectiveness of reducing errors in management accounting systems with respect to organizational performance. In particular, different basic design options of management accounting systems of how to improve the information base by measurements of actual values are analyzed in different organizational contexts. The paper applies an agent-based simulation based on the idea of NK fitness landscapes. The results provide broad, but no universal support for conventional wisdom that lower inaccuracies of accounting information lead to more effective adaptation processes. Furthermore, results indicate that the effectiveness of improving the management accounting system subtly interferes with the complexity of the interactions within the organization and the coordination mode applied.**

***Keywords* — Agent-based Simulation; Complexity; Coordination; Learning; Management Accounting Systems**

I. Introduction

MANAGEMENT ACCOUNTING is intended to provide decision-makers with judgmental information for evaluating options and to produce information for assessing managerial performance [1], [2].. For deciding whether, or not, to change the status quo in favor of an alternative option, a decision-maker requires information on the pay-offs of both options. Information related to the status quo may result from measurements of actual values (i.e., “weighting”, “counting” and valuing) within accounting systems; and unfortunately, it cannot be taken for granted that these measurements perfectly reflect reality [3]. The alternative options, in principle, are subject to ex ante-evaluations by decision-makers who, according to Simon [4] may suffer from cognitive limitations. However, also ex ante-evaluations might be based on measurements, i.e., actual values received on basis of decisions made in former periods and used to “learn” for future decisions. For instance, plan cost accounting often relies on cost functions which are built from actual costs realized in former periods [5] - or as Christensen} [3] puts it: “[o]nly autocorrelation makes historical accounting relevant for decision purposes” (p. 1827).

Moreover, management accounting systems are embedded in an organizational structure and the organizational structure affects imperfections of judgmental information. In particular, in organizations the overall decision problem is segmented into partial decisions which are delegated to decentral decision-makers (e.g., [6]-[8]). With delegation further difficulties occur: partial decisions may be interdependent, decision-makers likely have different information and pursue their own objectives opportunistically. To avoid losses with respect to the organization's performance, coordination is required, though, according to Ackoff [9], more intense coordination not necessarily increases organizational performance.

Against this background the paper investigates the following research question: *In which settings of organizational structure and basic design options of the management accounting system it is effective to use measured actual values by management accounting systems for improving judgmental information?*

Hence, the paper focuses on *imperfect knowledge of pay-off functions* in organizations. The paper does not address decision-making under uncertainty due to imperfectly known future events [10]. Furthermore, the paper does not consider the diverse biases and heuristics that individuals suffer from in case of uncertainty [11]. We regard accounting errors in terms of *noise as the difference between estimated and correct values* [12]. [13]; however, the paper does not relate to biases in accounting in terms of the application of accounting principles that is not in line with the accounting principles.

For investigating the research question, a method is required that allows controlling a multitude of issues in interaction with each other like interdependent decisions, coordination mechanisms, inaccuracies of judgmental information and related adjustments due to measurement of actual values by accounting. Obviously, these interrelated issues would be particularly difficult to control in empirical research and would induce intractable dimensions in formal modeling. In contrast, simulation methods allow dealing with manifold inter-dependent issues [14]. Since the research question focuses on collaborative decision-making an agent-based simulation appears appropriate.

The paper contributes to research since, to the best of the author's knowledge, for the first time different settings of memorizing actual values and dynamic adjustments through

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actual values in management accounting are investigated in interaction with major organizational design variables. Moreover, using an agent-based method is a relatively new approach in the area of management accounting ([15]-[18]).

The remainder of this article is organized as follows: Section II places the research question within the context of related literature. In the third chapter we introduce the simulation model and in Section IV we present and discuss results of the simulations.

II. Related Literature in Accounting and Organization Science

The research question of this article obviously refers to the body of research on errors in accounting. However, our study might also be seen in the context of research on a more general question: how does organizational design influence the overall outcome of an organization with decision-makers imperfectly informed about the outcome of alternatives? Subsequently, we outline these streams of research with respect to the research question addressed in this paper.

A. *Errors in Accounting*

Christensen [3] gives a recent overview and discussion on errors in accounting. Stating that errors in accounting are “often neglected when the design of accounting systems is evaluated” (p. 1836) he elaborates three dimensions of this subject. Firstly, accounting information serves to update expectations of future events of the firm (e.g., future costs, cash flows). In this sense accounting is a source of learning and, in particular, allows updating beliefs. Thus, the main question is whether the accuracy of information known beforehand and the accounting information leads to more reliable expectations about future events.

Secondly, Christensen [3] points out that particularly cost accounting in various contexts is based on linear cost functions and that linearity does not necessarily reflect reality perfectly. Thus, the accounting system suffers from an endogenous error. This line of argumentation also relates to the findings of Datar and Gupta [19] who analyze the effects of erroneous choices of cost drivers in product costing and to the findings of Labro and Vanhoucke [20] related to the interactions among errors in activity based costing. Recently, Leitner [16], [17] investigates interactions among errors and biases in traditional costing systems.

Thirdly, Christensen [3] states that accounting information not necessarily is the best sort of information for a certain purpose and that, for example, the price mechanism might reveal better condensed information. In this sense, applying accounting systems rather than, for example, the market mechanism is the erroneous choice.

B. *Imperfect Information on Pay-Off in Organizations*

The seminal work of Sah and Stiglitz [21]-[23] may be regarded as the starting point of the stream of research which investigates the robustness of different organizational structures against so-called type I and type II errors: In analogy to statistical inference, imperfect information used in decision-making basically can lead to two different types of errors: in case of “type I errors” an option that, in fact, is superior compared to the status quo is rejected due to a false negative ex ante-evaluation. In contrary, with “type II errors” a false positive option is chosen since it is perceived to be superior to the status quo, whereas, in fact, it is inferior.

In their 1986 paper Sah and Stiglitz [22] introduce a project-selection-framework: An organization consists of several decision-making units which receive knowledge of feasible projects. Imperfect ex ante-evaluations could occur in case that a “good'” project which, in fact, would increase organizational performance is rejected (type I error) or if a “bad” project which, in fact, reduces organizational performance is accepted (type II error). Each decision-making unit is characterized by a screening function. The screening function gives the probability that a project is accepted as a function of the project's quality, i.e., the project's contribution to performance.

Sah and Stiglitz [22] distinguish two “architectures” of the decision-making organization: polyarchy and hierarchy. In the polyarchy, each decision-maker can decide in favor of a project independent from other decision-makers. In the hierarchy, in case that a decision-maker on a lower level positively evaluates a project, the project proposal has to be forwarded to a decision-making unit of a higher level. Thus, for acceptance in a two-level hierarchy, a project has to be positively evaluated twice. Sah and Stiglitz [22] show that the hierarchy reduces the likelihood that projects are accepted which better should have been rejected, i.e., hierarchies reduce type II errors; in contrary, in a polyarchic structure the tendency to falsely reject “good” projects, i.e., the occurrence of type I errors, is reduced.

The works of Sah and Stiglitz initiated further research on the decision-making properties of hierarchical versus polyarchic organizations. For example, Koh [24], [25] introduces costs for information gathering and processing on the decision-makers site and information asymmetries related to the decision-makers actions into the project-selection-framework. In the study of Visser [26] the decision-making units do not suffer from errors in their judgments but rather from obstacles to fully communicate the information they have to other decision-making units. Christensen and Knudsen [27] extend the work of Sah and Stiglitz [21]-[23] by investigating the range of organizational structures between polyarchy and hierarchy and provide a general framework for designing decision-making structures that most effectively reduce type-I and type-II errors.

It is worth mentioning that some aspects of complex decentralized decision-making systems might differ from the project-selection-framework of Sah and Stiglitz: the projects under evaluation are independent from each other, i.e., no interactions between the single project options (or decisions) exist. However, there are also decision problems which cannot be segmented without inducing interactions among partial decisions and, to some extent, interactions are a consequence of specialization. The approach presented subsequently takes segmented decisions with interactions among partial decisions into account.

III. Simulation Model

The simulation model is based on the NK model introduced by Kauffman [28], [29] of evolutionary biology and successfully applied in management research (e.g. [30]-[32], for an overview [33]). The NK model allows representing a multi-dimensional decision problem where N denotes the number of dimensions and K the level of interactions among these dimensions. However, so far the NK model has rarely been employed to analyze decision-making with imperfect judgmental information [15], [18], [34].

We adopt an advanced version of the NK model with noisy fitness landscapes, as introduced by Levitan and Kauffman [34]. In particular, to analyze our research question the model consists of three components which are presented in the subsequent sections: (1) the organizational structure which is mapped similar to Siggelkow and Rivkin [31]; (2) a representation of imperfect judgmental information that corresponds to organizational segmentation and specialization; (3) alternative modes of how inaccuracies in judgmental information might be reduced in the course of the adaptive walks by measurements by the management accounting system. Thus, the components (2) und (3) are regarded to be the distinctive features of the model.

A. Organizational Structure

In each time step t of the overall observation period T the artificial organizations face an N-dimensional binary decision problem $\mathbf{d}_t = (d_{t,1},\ldots d_{t,N})$, i.e., they have to make decisions $d_{t,i} \in \{0, 1\}$ and $i = 1,\ldots N$. Each single state of decision $d_{t,i}$ provides a contribution $C_{t,i}$ with $0 \leq C_{t,i} \leq 1$ to organizational performance $V(\mathbf{d}_t)$. A decision $d_{t,i}$ might interact with K other decisions (for simplicity K assumed to be stable over time). Hence, K can take values from 0 (no interactions) to N-1 (maximum interactions). Thus, performance contribution $C_{t,i}$ may not only depend on the single decision $d_{t,i}$ but also on K other decisions so that

$$C_{t,i} = f_i(d_{t,i}, d_{t,i}^1, \ldots, d_{t,i}^K) \tag{1}$$

In line with the NK model, we assume that for each possible vector $d_{t,i}, d_{t,i}^1, \ldots, d_{t,i}^K$ the value of $C_{t,i}$ is randomly drawn from a uniform distribution over the unit interval, i.e., U[0,1]. Hence, given equation 1, whenever one of the states $d_{t,i}, d_{t,i}^1, \ldots, d_{t,i}^K$ of the single decisions is altered, another (randomly chosen) performance contribution $C_{t,i}$ becomes effective. The overall performance $V(\mathbf{d}_t)$ is given as normalized sum of performance contributions $C_{t,i}$ with

$$V(\mathbf{d}_t) = \frac{1}{N}\sum_{i=1}^{N} C_{t,i} = \frac{1}{N}\sum_{i=1}^{N} f_i(d_{t,i}, d_{t,i}^1, \ldots, d_{t,i}^K) \tag{2}$$

Our organizations consist of a main office and R departments subscripted by r. Each department has a department head. Our organizations segment their N-dimensional decision problem $\mathbf{d}$ into R disjoint partial problems and delegate each partial problem to one of the R departments. Hence, each department has primary control over a subset of the N single decisions $d_{t,i}$ (e.g., in case of $N = 10$ and $R = 3$ department 1 over decisions 1 to 3, department 2 over decisions 4 to 7 and department 3 over decisions 8 to 10), and from the perspective of a certain department r the organizational decision problem is partitioned into a partial decision vector $\mathbf{d}_{t,r}^{own}$ related to those single decisions which are in the "own" responsibility and into $\mathbf{d}_{t,r}^{res}$ for the "residual" decisions that other departments are in charge of. However, in case of cross-departmental interactions, choices of a certain department may affect the contributions of decisions other departments are in charge of and vice versa.

In each period t of the adaptive walk a department head seeks to identify the best configuration for the "own" subset of choices assuming that the other departments $q = 1,\ldots R$ and $q \neq r$ do not alter their prior subsets $\mathbf{d}_{t-1,q}^{*own}$ of decisions. In each time period a department head randomly discovers two alternative partial configurations of those binary decisions that he/she is in charge of: an alternative configuration $\mathbf{d}_{t,r}^{a1}$ that differs in one decision (a1) and another alternative $\mathbf{d}_{t,r}^{a2}$ which differs in two decisions (a2) compared to the status quo, i.e., $\mathbf{d}_{t-1,r}^{*own}$. In each time period department head has three options to choose from, i.e., keeping the status quo $\mathbf{d}_{t-1,r}^{*own}$ and the two alternatives $\mathbf{d}_{t,r}^{a1}$, $\mathbf{d}_{t,r}^{a2}$. According to economic literature, a department head favors that option which he/she perceives to promise the highest value base for compensation. In our model department heads are compensated on basis of the *overall* performance of the organization according to a linear incentive scheme so that we can ignore conflicts of interests between the organizational and departmental objectives.

However, due to specialization our department heads have different knowledge about the organization's decision problem $\mathbf{d}_t$ (we return to that point in the section III.B). In consequence, even though in our model no conflicts of interests occur, departments can have different preferences which might evoke a need for coordination. We analyze two different modes of coordination (for these and other modes [31], [36]):

– In the "decentral" mode, in fact, there is no coordination: each department autonomously makes the "own" partial decisions $\mathbf{d}_{t,r}^{own}$ and the overall configuration $\mathbf{d}_t$ of decisions results as a combination of these departmental choices without any central intervention. Hence, the function of the main office is limited to (perhaps inaccurately) observing the overall performance achieved.

– In a mode named "proposal" each department proposes two alternative configurations $\mathbf{d}_t$ to the main office and, among all proposals received, the main office finally chooses the one that promises the highest overall performance. Hence, by their proposals the departments shape the search space of the main office.

B. Informational Structure

Our agents identify superior solutions of the decisional problem according to the *perceived* contributions of the choices to their compensation or to overall performance, respectively. To represent inaccurate judgmental information - which might be improved due the management accounting system in the course of the adaptive walk (Section III.C) - we add noise on the contributions of decisions to performance. Furthermore, in order to represent expertise related to segmentation and specialization we differentiate noise according to the information quality different decision-makers in an organization reasonably have. A common idea of many organizational theories is that decision-makers in organizations dispose of information with different levels of imperfections (e.g. [7], [8]). For example, departmental decision-makers are assumed to have relatively precise information about their own area of competence, but limited cross-departmental knowledge whereas the main office might have rather coarse-grained, but organization-wide information.

We assume that departments decide on basis of the perceived value base for compensation, i.e., the perceived overall performance rather than the actual. Therefore, we "distort" the actual performance contributions according to the expertise of each single department. In particular, the perceived value base for compensation, i.e., the overall performance $\tilde{V}_{t,r}(\mathbf{d}_t)$ department r perceives, is computed as normalized sum of the actual own performance and actual residual performance, each distorted with an error term

$$\tilde{V}_{t,r}(\mathbf{d}_t) = [\tilde{V}^{own}_{t,r}(\mathbf{d}^{own}_{t,r}) + \tilde{V}^{res}_{t,r}(\mathbf{d}^{res}_{t,r})] \big/ N \qquad (3)$$

where

$$\tilde{V}^{own}_{t,r}(\mathbf{d}^{own}_{t,r}) = V^{own}_{t,r}(\mathbf{d}^{own}_{t,r}) + e^{own}_r(\mathbf{d}^{own}_{t,r})$$
$$\text{and } \tilde{V}^{res}_{t,r}(\mathbf{d}^{res}_{t,r}) = V^{res}_{t,r}(\mathbf{d}^{res}_{t,r}) + e^{res}_r(\mathbf{d}^{res}_{t,r}) \qquad (4)$$

Likewise, in the coordination mode "proposal" the main office makes a choice from the proposals on basis of the *perceived* overall performance $\tilde{V}_t(\mathbf{d}_t)$ computed as the sum of the true overall performance $V_t(\mathbf{d}_t)$ and an error term $e_{main}(\mathbf{d}_t)$.

At least with respect to accounting systems [20], it is reasonable to assume that high (low) true values of performance come along with high (low) distortions. Hence, we reflect distortions as *relative errors* imputed to the true performance (for other functions [35]). , and, for simplicity, the error terms follow a Gaussian distribution N(μ;σ) with expected value $\mu = 0$ and standard deviations σ^{own}_r, σ^{res}_r and σ_{main}. For example, department r perceives the "own" performance as

$$\tilde{V}^{own}_{t,r}(\mathbf{d}^{own}_{t,r}) = V^{own}_{t,r}(\mathbf{d}^{own}_{t,r}) \cdot (1 + N(0; \sigma^{own}_r(\mathbf{d}^{own}_{t,r})) \qquad (4^*)$$

We differentiate the standard deviations according to specialization of departments and the main office as mentioned above (see notes on parameter settings in Table 2).

C. Basic Design Options of the Management Accounting Systems

As argued in the introduction, within the search for higher levels of performance ex ante-evaluations might suffer from two deficiencies: The performance of the status quo option is misestimated and/or the performances of alternative options are inaccurately evaluated. This paper is particularly interested in the potentially beneficial role that measurements of the status quo by accounting systems can play for organizational performance. In our model, we therefore distinguish five settings of measurement and usage of actual values in the adaptive walk (summarized in Table 2) which may be regarded as basic design options of the management accounting system:

TABLE I
SETTINGS OF MEASUREMENT AND USAGE OF ACTUALS IN THE ADAPTIVE WALKS

Name of Setting	Measurement of Actuals for Status Quo	Adjustment of Inaccuracies in Adaptive Walk
(1) No measurement	no	no
(2) Measurement only	yes	no
(3) Stepwise refinement	yes	stepwise
(4) Immediate adjustment	yes	immediately at once
(5) Perfect evaluation	yes	(not necessary)

1) In case that "no measurement" is used the evaluation of the status quo configuration (i.e., the choice $\mathbf{d}^*_{i-1}$ made in period t-1) cannot be based on the measurement of the actual values achieved in the previous period. In a way, this reflects an organization which does not have any accounting system at all.
2) In a setting we call "measurement only" our departments use accounting systems which allow them to perfectly determine the performance that was achieved with the status quo configuration $\mathbf{d}^*_{i-1}$ of the decisional vector. Hence, throughout each adaptive walk, when department heads decide they perfectly get informed about the status quo by the accounting system. However, they suffer from inaccurate knowledge of the performance contributions of the alternative options $\mathbf{d}^{a1}_{t,r}$ and $\mathbf{d}^{a2}_{t,r}$, that they consider, i.e., the accounting system does not provide any refined information on the alternatives regardless of whether they have been implemented in the past or not. Thus, the accounting system does not provide any tracking or memory about the configurations that have been realized

or any information for updating of beliefs (s. section II.A) on the alternative options.

3) A setting we name "stepwise refinement" goes a step further. Like in the previously described setting the decision-makers get perfect information about the performance of the status quo $\mathbf{d}_{i-1}^{*}$, and, *additionally*, the measured actual values are used for some kind of "learning". Hence, the management accounting system is used for updating of beliefs on alternative options according to [3]. For simplicity the stepwise refinement is represented in a relatively "mechanistic" form of noise reduction: whenever a certain configuration **d** of decisions has been implemented, decision-makers receive information about the related contributions to performance measures. This information will be partially memorized in future periods, and, in particular, will then lead to a refined estimation of performance of that configuration. This situation, for example, reflects a situation where cost functions applied for cost planning might be (even automatically) adjusted with each measurement of the performance that a certain configuration of cost drivers provides: with each determined combination of cost drivers and cost measures the statistical basis is broadened from which a cost function could be derived (for example by regression analysis). For each of the $n = 2^N$ configurations $\mathbf{d} = (d_1,\ldots d_N)$ in the solution space (due to $d_i \in \{0, 1\}$ and $i = 1,\ldots N$) a counter $count^n$ is introduced. Whenever a certain configuration **d*** is chosen/implemented during the observation period T the related counter $count^{d^*}$ of configuration **d*** is incremented by 1. Hence, if the performance contributions of this configuration **d*** are evaluated again in a later period the corresponding errors e_r^{own}, e_r^{res} and e_{main} are divided by $count^{d^*}$. Thus, for example, when under coordination mode "proposal" the main office again evaluates configuration $\mathbf{d}_t$ the main office perceives the overall performance as

$$\tilde{V}(\mathbf{d}_t) = V(\mathbf{d}_t)\cdot\left(1+\frac{1}{count^{d_t}}\cdot e_{main}(\mathbf{d}_t)\right) \tag{5}$$

4) The case "immediate adjustment" slightly differs from the "stepwise refinement" setting as the accounting systems provide perfect memorizing and immediate correction of ex ante-evaluations due to measured actual values for a configuration **d*** that has been implemented. Hence, whenever in the adaptive walk a configuration is considered, which has already been implemented, at least once, during the walk, the decision-makers get perfect information about the level of performance as measured by the accounting system. For example, the main office evaluates the overall performance of a configuration $\mathbf{d}_t$ as

$$\begin{aligned} &\tilde{V}(\mathbf{d}_t) = V(\mathbf{d}_t)\cdot(1+e_{main}(\mathbf{d}_t)) \text{ for } count^{d_t} = 1 \\ &\tilde{V}(\mathbf{d}_t) = V(\mathbf{d}_t) \text{ for } count^{d_t} \geq 2 \end{aligned} \tag{6}$$

5) Perfect evaluations in our simulations serve as a "benchmark" so that performance differences due to imperfect evaluations can be determined. Here neither the evaluations of the status quo $\mathbf{d}_{i-1}^{*}$ nor of the alternative options $\mathbf{d}_{t,r}^{a1}$ or $\mathbf{d}_{t,r}^{a2}$ suffer from any noise, i.e., all error terms are set to zero.

IV. Results and Interpretation

A. Parameter Settings in the Simulation Experiments and Measures for Effectiveness

For simulating an adaptive walk, after a "true" fitness landscape is generated, distortions are added which follow the informational imperfections in the organization as described in section III.B. Then the organizations are placed randomly in the fitness landscape and observed for 300 periods while searching for higher levels of organizational performance under the regime of various settings of management accounting systems as introduced in section III.C. As is familiar for adaptive walks we use a hill-climbing algorithm. In particular, each decision maker evaluates the options he/she knows (i.e., status quo and alternatives) and an alteration is preferred in favor of that option which promises the steepest ascent.

The results were conducted for two interaction structures of decisions (i.e., coordination needs) which, in a way, represent two extremes (for these and other interaction structures see [32]): in the low complexity case intra-departmental interactions among decisions are maximal intense while no cross-departmental interdependencies exist. This type of interactions corresponds to a "self-contained" organization structure [7] and comes close to a pooled interdependence [37], [38]. In contrast, in the high complexity case all decisions affect the performance contributions of all other decisions, i.e., the complexity of interactions and the coordination need is raised to maximum. This situation comes closest to a reciprocal interdependence [37], [38].

Empirical findings report errors of judgmental information between 5 up to 30 percent [39], [40]. Results presented in this paper relate to errors around 10 percent though differentiated due to specialization as described in section III.B and as explicated in the note to Table 2. (It is worth mentioning, that results were subject to robustness analyses, especially with respect to the magnitude of errors and the spread between knowledge about the "own" area of competence and the rest of the organization. We found that the results appear robust in a range up to a magnitude of overall error around 22 percent and with several levels of spread according to specialization of decision-makers.)

For investigating the effectiveness of the adaptive walks we rely on three measures as displayed in Table 2: "Speed (V_5–V_1)" reports the performance enhancements achieved in the first 5 periods within the adaptive walks. This measure appears interesting because in the first periods most purely the

TABLE II
CONDENSED RESULTS

Name of Setting	Low Complexity Speed (V_5-V_1)	Low Complexity Final Performance (V_{300})	Low Complexity Frequency of Global Maximum in t = 300	High Complexity Speed (V_5-V_1)	High Complexity Final Performance (V_{300})	High Complexity Frequency of Global Maximum in t = 300
Decentral Mode						
(1) No measurement	0.04419	0.83689	1.66 %	0.12479	0.84374	1.94 %
(2) Measurement only	0.05211	0.85251	1.94 %	0.12488	0.86941	3.16 %
(3) Stepwise refinement	0.05734	0.89748	8.24 %	0.12818	0.86738	3.00 %
(4) Immediate adjustment	0.05771	0.89381	7.76 %	0.12121	0.86519	3.46 %
(5) Perfect evaluation	0.07321	0.89730	10.16 %	0.14536	0.86466	2.44 %
Proposal Mode						
(1) No measurement	0.06878	0.83506	1.46 %	0.05739	0.83541	1.76 %
(2) Measurement only	0.07277	0.85222	2.52 %	0.05754	0.83665	1.90 %
(3) Stepwise refinement	0.08473	0.87681	4.84 %	0.06387	0.85041	2.30 %
(4) Immediate adjustment	0.08601	0.87724	4.56 %	0.06742	0.84803	1.78 %
(5) Perfect evaluation	0.09781	0.89518	9.54 %	0.06510	0.86716	2.40 %

Notes: Each entry represents results of 5,000 adaptive walks: 1,000 distinct fitness landscapes with 5 adaptive walks on each over 300 periods. Confidence intervals for V_{300} at a confidence level of 0.001 range between ±0.003 and ±0.004. Common parameters in settings (1) to (4): $\sigma_r^{own} = 0.05$, $\sigma_r^{res} = 0.15$ and $\sigma_{main} = 0.1$ (in (5) all set to 0); all errors with expected value $\mu = 0$.

effects of refinements (settings 3 and 4) can be observed. The performance in the last observation period V_{300} can serve as an indicator for the effectiveness of the search process as well as the frequency of how often the global maximum in the performance landscape is achieved in the last period observed.

Furthermore, Fig. 1 and Fig. 2 reflect the performance differences in the course of the adaptive walks of the noisy against the perfect evaluations for low and high complexity of cross-departmental interactions.

We discuss results in two steps. Firstly, we focus on comparing the different settings of measuring and using actuals against each other (Section IV.B) and afterwards we discuss the moderating effects of complexity and coordination (Section IV.C).

B. Effectiveness of Various Settings of Management Accounting Systems

Obviously, evaluating alternative options with imperfect information can result in a choice which *appears* favorable, whereas, in fact, it reduces performance compared to the status quo ("false positive" decision) [35]. Underestimating the status quo level of performance due to missing or imperfect measurement of actuals might foster the false estimation. Vice versa, with "false negative" decisions an alternative is rejected because its marginal contribution to performance compared to the status quo appears worse than it actually is and, thus, the status quo is perpetuated [35]. This situation may be fostered by an overestimation of the status quo level of performance. These considerations let us hypothesize the following:

With increasing levels of measurement and usage of actual values for improving judgmental information (1) the speed of performance enhancements increases and (2) higher levels of organizational performance are achieved.

The five settings of management accounting systems in terms of measuring actual values and using these numbers for judgments as displayed in table 1 incorporate an order of increasing information accuracy. We find that the speed measure (V_5–V_1) in Table 2 in most cases is increasing with the more advanced settings of accounting systems. Furthermore, as Fig. 1 and Fig. 2 show at a glance, the more advanced settings of management accounting systems tend to have lower performance losses against the perfect system. However, the results provide broad, but no universal support for the hypothesis stated above and some of the results deserve a closer analysis.

First of all, it is worth mentioning that under setting (1) where no actual numbers are available at all, the performance achieved is lowest in all of the four scenarios of coordination need and mode -- in three scenarios with remarkable performance losses even to the "measurement only" setting (we discuss the "high complexity-proposal mode"-scenario below more into detail). Apparently, over- or underestimating the status quo leads to severe losses of speed and level of performance enhancements. *Hence, this indicates that using an accounting system, at least, to track the status quo (e.g., an actual cost system) is effective.*

Secondly, the results for the "stepwise refinement" and the "immediate adjustment" are rather similar for all scenarios under investigation. An obvious reason is that the "stepwise refinement" setting is modeled in a way that the decision-makers get better knowledge of the fitness landscape relatively fast. The simulation of a slower learning curve might yield other results.

Thirdly, "stepwise refinement" and "immediate adjustment" of knowledge about the fitness landscape bring performance to levels higher than achieved with "measurement only" -- except for the case of high complexity and decentral coordination which is discussed in section IV.C. Obviously, it is less likely

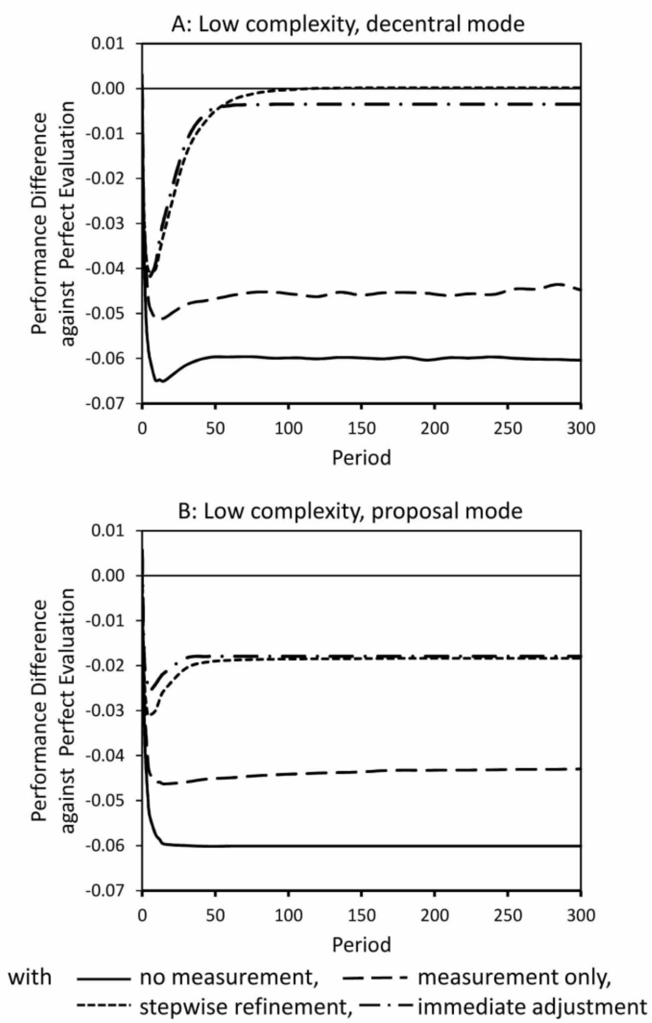

Fig. 1. Performance differences against perfect evaluations in case of no cross-departmental interactions
Notes: The horizontal line at level 0 of the y-axis reflects the perfect evaluation and the other lines represent the performance differences in the course of the adaptive walks against the perfect management accounting system. Each line represents results of 5,000 adaptive walks: 1,000 distinct fitness landscapes with 5 adaptive walks on each over 300 periods. For parameter settings see Table 1 and notes to Table 2.

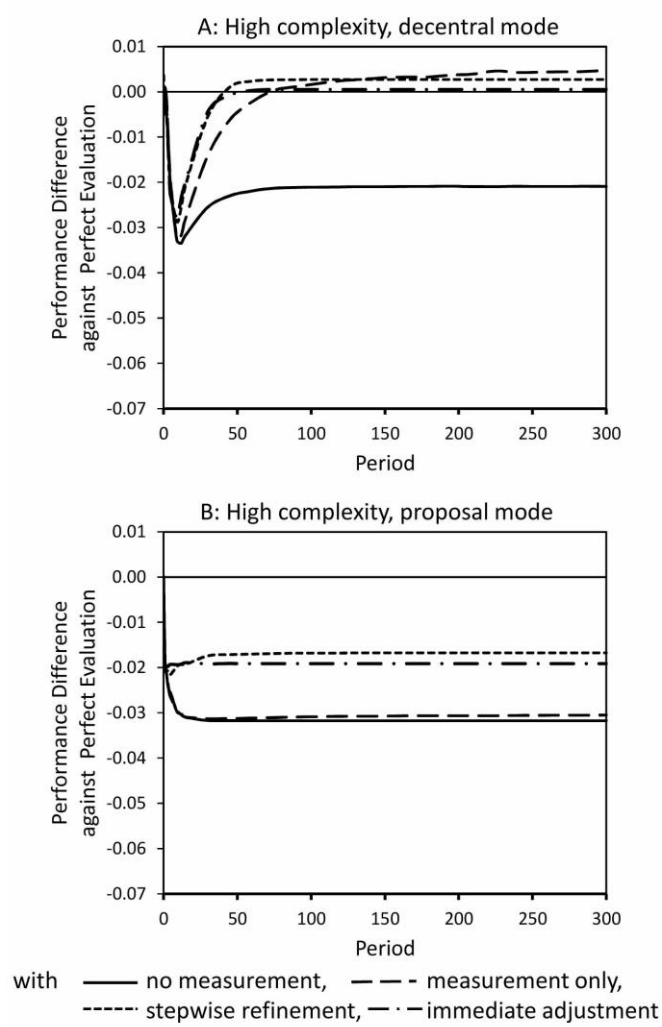

Fig. 2. Performance differences against perfect evaluations in case of maximum cross-departmental interactions
Notes: The horizontal line at level 0 of the y-axis reflects the perfect evaluation and the other lines represent the performance differences in the course of the adaptive walks against the perfect management accounting system. Each line represents results of 5,000 adaptive walks: 1,000 distinct fitness landscapes with 5 adaptive walks on each over 300 periods. For parameter settings see Table 1 and notes to Table 2.

to opt for a false positive or false negative alternative within the adaptive walks in case of the immediate or stepwise improvement of judgmental information by actuals. *This indicates that accounting systems which allow memorizing actual values contribute to higher performance levels.*

C. Effects of complexity and coordination mode

The results provide broad support for intuition that increasing accuracy of the management accounting systems captured in settings 1 to 5 leads to faster performance enhancements und higher levels of final performance. However, some results run contrary to intuition. In particular, the complexity of the interactions structure (i.e., coordination need) and the coordination mode applied apparently interfere with the information accuracy provided by the management accounting system.

We start the discussion of the effects of coordination need and mode with the scenario of "low complexity-decentral mode" (Fig. 1A). In this case no cross-departmental interactions exist. Therefore, no cross-departmental coordination is required: with imperfect judgmental information departments might decide in favor of a suboptimal partial option (false positive or false negative), but there are no external effects in the sense that this would reduce the performance of the other departments' decisions. The accounting systems 3 and 4, after around 75 periods in average reach the level of perfect information while systems 1 and 2 induce a rather high, nearly constant distance to perfect evaluations.

To a certain extent, things seem to change for highly intense cross-departmental interactions among decisions (Fig. 2A). In particular, with decentral coordination for high complexity even the "measurement only" setting leads to performance levels *beyond* that achieved with perfect evaluations. Fig. 2A indicates that after around 50 to 75 periods the noisy accounting systems with measurements of actuals (i.e. settings (2), (3) and (4) in table 1) *exceed* the performance achieved with perfect evaluations.

In order to provide an explanation for this “beneficial” effect of noise we refer to “false positive” evaluations. Of course, with “false positives” an organization goes a “wrong way" for a short term, but with the chance to discover superior configurations in a longer term [15], [34]. In particular, imperfect knowledge may afford the opportunity to leave a local peak in the fitness landscape. We argue that this effect is the more likely the more interactions among decisions exist: as is well investigated for the NK model in literature (e.g. [29], [30]), with higher levels of complexity the more rugged is the fitness landscapes and the more local maxima exist, and, hence, the search process is more likely to stick to a local maximum. Inaccuracies induce diversity in the search process, and “false positive” alterations, though short-term harmful, provide the chance to discover superior levels of performance and, eventually, the global maximum in the long-term. The results provide support for this intuition: In the “high complexity-decentral mode” scenario the relative frequency of how often the global maximum is found is lower with perfect evaluations than with noisy accounting systems as far as they measure the status quo.

In the next step we analyze the role of the *coordination mode*. Firstly, results indicate that with the proposal mode (i.e., with involving the main office in decision-making) the range of differences in speed and level of performance among the various forms of management accounting systems. Hence, in a way, *with introducing the information-processing power of the main office the relevance of the setting of the accounting system tends to be reduced*.

Secondly, our results (Fig. 1A versus 1B and Fig. 2A versus 2B) also suggest that with inaccurate judgmental information in the proposal mode organizations miss the chance to achieve those performance levels that can be reached with perfect evaluations. In order to provide an explanation we find it helpful to remember that in the proposal mode the status quo only is abandoned if two conditions are met. First, at least, one department has to discover a partial vector that promises a higher compensation to the respective department head (otherwise he/she would not propose the alteration); second, the main office has to accept the proposal. Hence, for being implemented each proposal has to pass an additional instance and, hence, it is less likely that false positive evaluations on the departments' site affect final decisions since the main office may detect the false positive evaluations [22].

However, by that, the “false positives” are less likely to do their beneficial work as discussed above. Furthermore, “false negative” evaluations by the main office might occur and the organization is more likely to suffer from inertia compared to the decentral mode. With more inertia the fitness landscape is less likely to be “explored” and this reduces benefits of the “stepwise refinement” and “immediate adjustment” accounting systems: To enfold the full potential of “learning” management accounting systems (settings 3 and 4) a certain exploration of the decisional space is required, which apparently might not be given in the proposal mode.

V. Conclusion

The results provide broad support for the intuition that improving judgmental information by measurements of actual values in management accounting systems leads to more effective adaptive search processes for higher levels of organizational performance.

However, the results might throw some new light on basic design choices of management accounting systems: apparently, the contribution of improving information accuracy in management accounting systems subtly interferes with coordination need and mode. In particular, results do not universally support conventional wisdom that better accounting systems are more beneficial when decision-problems are highly complex. Furthermore, our results suggest that inaccuracies might have their positive sides compared to perfect information for complex decisions - given that inaccuracies are accompanied by decentral coordination.

Moreover, it appears that with more central coordination the relevance of improving information quality in the management accounting system decreased. In short, to a certain extent management accounting systems and central coordination power seem to serve as substitutes. Hence, taking into account that improvements of management accounting systems usually are not costless, these findings put claims for investments in perspective.

At the same time, our analysis is subject to several limitations which should be overcome in further research. First of all, it should be mentioned that in our model the contributions of management accounting systems to ex ante-evaluations of alternatives is represented in a rather coarse way. Of course, more sophisticated learning and forecasting methods could be integrated (i.e., methods applied in plan cost accounting systems). Moreover, the ex ante-evaluations of our decision-makers suffer from imperfect knowledge about the “production functions” (in terms of the relation between choice and organizational outcome), but the model presented does neither reflect conflicts of interests nor decision-making under uncertainty. Obvious extensions of the model could overcome these shortages, especially in order to address the function of management accounting systems to update beliefs of decision-makers as elaborated by Christensen [3].

Furthermore, organizations apply various strategies and coordination modes to deal with imperfectly known “production functions”. In further extensions these strategies could be reflected in the model as well as the decision-making biases (e.g., status-quo bias) that decision-makers suffer from [11]. Including these aspects could reveal further insights into the relative benefits of basic design options of management accounting systems.

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Reality and perspectives of a model for the population that obtains its income with the use of an animal-drawn vehicle in the city of Bogota

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***Abstract* — This paper analyzes the structure of the data collected in the population dependent or receives its revenues in the use of animal-drawn vehicle, to extract an economic model for the development of this activity (which is currently done with these vehicles and is unbusinesslike) introducing formal parameters, as well as replacement of the vehicle analyzes the development of this activity in this population.**

***Keywords* — mobility, animal-drawn vehicles, traffic and transport, Management Models.**

I. Introduction

The District University in partnership with the District Department of Transportation developed the project "Technical, legal, financial and social withdrawal project drawn vehicles - Development of socioeconomic characteristics of the population of wheelwrights (VTA) in the city of Bogotá, including proposed scenarios viable and sustainable economic projects that replace and/ or technify animal-drawn vehicle (ATV) - Phase One" within the project results were compiled economic data how dependent people or receive their income from the use of animal-drawn vehicle, these data allowed, once processed, extracting an economic model for the development of this activity, yes, without neglecting the activity currently being undertaken with these vehicles is unbusinesslike, and it is necessary to begin entering parameters formalization of this activity, and it is also necessary to think of replacing the vehicle that is currently used for the development of this activity in this population.

II. Model Features

A. Population profile (VTA)

According to the results of the census conducted within the scope of the project and correspondence analysis conducted, it was concluded that the population of wheelwrights (VTA) is median age (35 years), with a level of education that is among the final years of primary school and early high school, living primarily in family, which has been established by cohabitation and share your home with children, siblings and parents.

The wheelwright (VTA) has chosen activity to the extent that his inner circle develops the same activity and in many cases, family members are jointly involved in the development of the tasks associated with the management of the wagon.

Those who engage in this activity are owners of his wagon and horses have it and not only a single set, which kept in proper condition. They live primarily in rented house and have access to basic services of water and energy, but do not have access to natural gas. Managing your garbage is done by the utility company, which shows the coverage of these services by district entities.

They usually work 8 to 12 hours or so and they do between Monday and Friday, but work on Saturday's noon. The wheelwrights made between 1 and 2 daily trips and their activity is directed mainly to recycling (glass, paper, plastic and metal mostly).

B. Current function of expenses (FAE)

Once the wheelwrights population profile (VTA), we found that this population group to perform an informal activity, manages its economy in the same way, though it was established that despite this, this population based his scheme of aggregate expenditures on two parameters, namely, home maintenance costs and maintenance of animal-drawn vehicle on one hand the cost of upkeep of the home, are part of the function of expenses, because the administrative, planning logistics and marketing strategies are developed within the family, where family members, act as administrators and managers in this task, so the costs of maintenance of the home are part of the expenditure function.

On the other hand, despite having no formal, expenditures for home maintenance costs resemble those of a home at any lower layer 3 and its calculation is based on:
Public services (SP), financing of housing ownership (AV), Food and cleanliness (AA), Education and Entertainment (EE) and Health and other minor expenses (SG). With the foregoing the calculation represented:

$$SO_n = SP_n + AV_n + AA_n + EE_n + SG_n, n = 1,2,3, \ldots etc.$$

For the schema of the function and its components, you can

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see that this equation tends to be constant, since a home tends to stabilize and maintain their support costs at a fixed interval of low variability, this situation is familiar to the road population, however in certain periods or the result of uncontrolled events, this equation may have variations from one period to another, in circumstances such as new household members, housing changes, external situations, etc.., so is must set the value of the equation to the conditions of the period, for the calculation of the function.

Moreover, within the expenditure function can find another cost parameter, and this is the maintenance of animal-drawn vehicle (MVTA), which as its name suggests answers to the calculation of the expenses incurred by animal-drawn vehicle , but unlike the upkeep of the home to calculate this equation, vary according to the use of animal-drawn vehicle in the period, because, for the calculation takes the following variables: Rent a manger + parking (APP), wagon rent + horse (ACE), horse maintenance expenses (GME) and expenses of the wagon (GMC), and the calculation is:

$$MVTA_n = APP_n + ACE_n + GME_n + GMC_n, n = 1,2,3 \dots etc.$$

Equation $MVTA_n$, can be divided into two parts viz, the first of these variables is associated with APP and ACE, which tend to assume positive values constant indifferent of using animal-drawn vehicle, ie tend to assume the same value period becoming a constant period at different times, but still and knowing this, these variables may fluctuate permanent possibilities event such as: horse change, change of parking, etc.., on the other hand have cost variables GMC and GME, unlike the first, these variables, as they tend to vary in relation to the use of animal-drawn vehicle in the period, since its value responds to the calculation of variables associated with the use of animal-drawn vehicle, so such as the fittings are costs to be incurred in the extent to which greater use of horses, the animal disease can become the occasion of contact with other horses or sites stay low hygiene, is more prone to traffic accidents in the extent to which the vehicle share the road with other vehicles, etc.

Having stated the above, the function of expenses $f(FAE)$, responds to the sum of the variables discussed above, adding the two groups given above, we can say that $f(FAE)$ it is equal to the sum of SO_n and $MVTA_n$, thus:

$$f(FAE) = SO_n + MVTA_n, n = 1,2,3 \dots etc$$

C. Current Income Function (FIA)

For the calculation of the income is part of the way the wheelwrights carry out their work, ie, what was found, once the information was collected, is that this population operates in an informal way, that its main activity is the collection of materials for recycling, that in addition to this recycling, also dedicated to the transport of debris or construction material, but despite this, payment is due on sale in gathering place of the weight in kilos of transported material, so as FIA current income due to the amount of trips transporting different types of materials on the day x the number of days worked in the period, being affected this relationship by the number of hours that a wheelwrights works on an ordinary day, the income also vary according to the mix of materials animal drawn vehicle transport to the collection center, the results of the field work showed that the main materials transported by the population (VTA) are: Glass (VI), paper (PA), Plastic (PLA) and metal (ME) for the most part, also found that some of them and in some specific days a week, can transport crates (GU), rubble (ES) or other not so frequently, the above revenue function, is given by the sum of the different materials in kilos put into the collection center or place of sale, multiplied by the sales price of the same:

$$f(FIA) = \sum_{i=1}^{n} P_i x MT_i$$

In equation P is the selling price per kilo material and MT is the type of material transported, on the other hand, this function has a restricted income, which refers to the ability of the animal-drawn vehicle in kilograms to transport material, as well as the carrying capacity of the wagon is associated with the ability to have the animal shot in the fieldwork, it was found that the majority of animals used in this work are light horses (under 650kg) and heavy, and although not common, were also found mules and other animals for these studies, we also found that animals for this work are mostly race called creoles and in a few cases were found mixed breeds animals as the percheron and Creole, apart from this, the capacity of these animals will vary according to the weight of the animal, the size of it, race horse over the animal, on the other hand, we also found that the cart, also influences the total load capacity, details such as the type of tires used, type mechanism in which the tires are mounted (bearings, etc.), the material of the structure and the slab; with the foregoing, the revenue function is:

$$f(FIA) = \sum_{i=1}^{n} P_i x MT_i$$

Subject to:

$$\sum_{i=1}^{n} MT_i \leq (k \ x \ PE) - (c \ x \ PC)$$

Where k is the coefficient associated with the load you can drag the equine, PE equine weight, c is the coefficient of the structure of the wagon (This will vary according to the maintenance of the wagon and supplies it) and finally PC the weight of the wagon.

Moreover wheelwrights population, despite developing its work in the informal, is no stranger to market behavior and the conditions thereof, so as the price of kilo of material at the point of collection will vary according to demand the same experience in the period, so as to offer more the price will tend to fall and less supply of the same the effect is opposite, that is, the price will tend to rise, the equation for this situation is first degree (linear) and can be generally represented as follows:

$$P = e \; x \; MT + P_{min}$$

Where the price will vary according to e who is modulus of elasticity, this is multiplied by the amount of material to sell, the equation is complemented with a minimum price or zero price of units, the behavior of the function vary according to the value of elasticity, which determines the slope of the same and the minimum price, the graph of the function behaves as in Figure 1, where the slope of the linear function defined by the falling price of the material with respect to the higher volume thereof.

Returning to the role of income and considering the variations with respect to prices previously explained, the new function of income will be:

$$f(FIA) = \sum_{i=1}^{n} (e \; x \; MT + P_{min})_i x MT_i$$

Subject to:

$$\sum_{i=1}^{n} MT_i \leq (k \; x \; PE) - (c \; x \; PC)$$

Operating, finally revenue function is:

$$f(FIA) = \sum_{i=1}^{n} (e_i \; x \; MT_i^2) + (P_{\min i} x \; MT_i)$$

Subject to:

$$\sum_{i=1}^{n} MT_i \leq (k \; x \; PE) - (c \; x \; PC)$$

But the market volume is finally defined by all potential revenue to be gained by selling materials and are tied to the demand function, this says that the market will have a maximum value, this maximum is the highest possible income that given material could produce.

For this value, the point of maximum revenue, would derive revenue function. This concept is called Marginal Revenue and the point of maximum income will be given when the value of the marginal revenue function is equal to 0 (zero), that is:

$$\frac{df(FIA)}{dMT} = \sum_{i=1}^{n} 2e_i \; MT_i + P_{\min i}$$

Where the value of the function is zero, find the maximum amount of material that can be sold without causing a decline in revenue.

D. Cash Flow Model

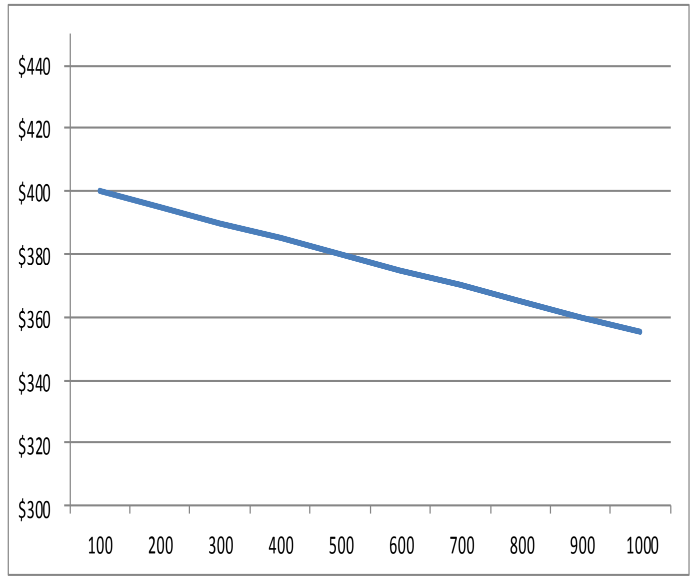

Fig 1. Sample materials demand function for A

Based on the income and expenses, we propose a cash flow model for recycling activity developed by the population of VTA wheelwrights, in this model is considered SO, MVTA as part of FIA expenditures and revenues as part of this is illustrated in Table 1.

This enclosure leads us to define the population of wheelwrights and to the activity as such the equation that helps us to establish the sustainability of the business and that is:

$$\frac{(f \; (FIA)_{n-1} - \; (SO_{n-1} + \; MVTA_{n-1})) + f \; (FIA)_n}{SO_{n+1} + \; MVTA_{n+1}}$$

Where should ensure that the income of the period plus the remaining amount of prior period do not exceed the amount of income in the period under review, according to information collected in the field and testimonials from community members themselves, is some periods sustainability of the activity tends to be below the minimum support value, a situation that forces people to wheelwrights to use strategies such as reducing maintenance costs of home sale or disposition of goods, loans informally with moneylenders, etc.

TABLE 1

CASH FLOW MODEL FOR POPULATION OF WHEELWRIGHTS (VTA)

	Month n	Month n+1	Month n+2
Income	$f\ (FIA)_n$	$f\ (FIA)_{n+1}$	$f\ (FIA)_{n+2}$
Functional Expenses	SO_n	SO_{n+1}	SO_{n+2}
Operating Expenses	$MVTA_n$	$MVTA_{n+1}$	$MVTA_{n+2}$
Total expenses	$SO_n + MVTA_n$	$SO_{n+1} + MVTA_{n+1}$	$SO_{n+2} + MVTA_{n+2}$
Cash	$f\ (FIA)_n - (SO_n + MVTA_n)$	$f\ (FIA)_{n+1} - (SO_{n+1} + MVTA_{n+1})$	$f\ (FIA)_{n+2} - (SO_{n+2} + MVTA_{n+2})$

E. Management Model

The population of wheelwrights uses a management model based on the immediate response to emerging needs, that is, the administrative management of money management is done in an informal way, no records of any kind logistics management is very poor or non-there since the horse-drawn vehicle begins the workday without fixed route plan, on the other hand the work of marketing and product advertising is not because the carters client is always the same and if generated these changes do not correspond to planning but rather for casual events, management of portfolio (by the way of work) is nonexistent and not allow credit sales, no inventory and manage transformation processes do not.

Therefore, management model of these business units is reduced to a daily revenue management, for these his two cost parameters: one for family and one for the vehicle, the savings are nonexistent, so no money reserves for contingencies and for modernization of the team, or for innovation or development.

The current management model that caused the population (VTA), carrying out business at a disadvantage with the rest of the population is engaged in the transportation of material, gradually forcing them to transform their business, in addition to this the animal-drawn vehicles are causing various problems such as traffic difficulties (low travel speeds faster avenues), accidents with horse (to force the horse to higher loads and work with food deficiency), the oversized loads, Insecurity (carts used in criminal acts, etc.).

Discussed above, we propose a management model should be based on the organization and distribution of income according to their obligations, they also organized into two categories: administrative and operating expenses. In the first should be organized and should include payroll and leases own activity and marketing efforts work and payments of financial obligations on the other hand, operating expenses must be related to logistics costs and vehicle maintenance costs.

III. RECOMMENDATIONS

When formalizing the processes, policies and tools oriented to the management and development of intellectual assets of the organization (in this case the District Department of Transportation Bogotá), with the aim of transforming the knowledge accumulated in value and benefits tangible to the organization and its stakeholders (other offices of the Mayor), we are talking about Knowledge Management.

We could say that the initial stage arose from the need of the District Department of Transportation to analyze the current situation and future projection VTA of resources and capacities of the city, designed to meet different scenarios, along with establishing a vision of the potential current and future (replacement) which will be based on the strategic development of the city traffic.

Given the importance of knowledge at a strategic level within the organization, there a next step that has generated the need for the development of a 'knowledge strategy', which forms the foundation for the success of the project in the organization. For this, being understood the context of the needs and projections set out in the strategy of knowledge and recognizing the degree of technological adaptability necessary for a development project.

Of course everything must start from the need for the wheelwrights to improve their working conditions and for this we examined the possibility technify your working tool, and this modernization is to change the binomial (wagon and horse) by a motorized means of transport base gasoline (motorcar) in addition to this is low power, high performance, reduce their travel time, increase their average speed, reduce operating costs, reduce maintenance costs and allow wheelwrights VTA, continue to make its core business, which at a later stage would be implementation.

In a globalized, knowledge management can be considered the organizational structure and culture that facilitates working together, sharing knowledge and information, physically and virtually, so that we are able to develop innovative products and services, new solutions and be more effective and effective.

Properly manage knowledge does not necessarily mean being more innovative, but it involves a solid foundation (in terms of culture, processes, policies and technologies) that can and should be used by the city as a lever for innovation and change

CONCLUSIONS

The model presented seeks to better explain the existing the way it performs the activity of the population derives its income from the use of animal-drawn vehicle, in addition to this, the model should also serve as input for the analysis retirement convenience or modernization of the working tool currently used wheelwrights (VTA).

With the above model can be analyzed as changes come to affect the activity of the population currently wheelwrights (VTA), this analysis can be performed independently of both the revenue of the activity, as the expenses of the same, with this you can develop strategies or mitigation and monitoring plans when making changes to the development of the activity.

Without proper knowledge management from top management enhanced with instruments suitable motivation and involvement, innovation becomes a process even more difficult, more distant and therefore much more expensive.

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Connecting possibilistic prudence and optimal saving

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***Abstract* — In this paper we study the optimal saving problem in the framework of possibility theory. The notion of possibilistic precautionary saving is introduced as a measure of the way the presence of possibilistic risk (represented by a fuzzy number) influences a consumer in establishing the level of optimal saving. The notion of prudence of an agent in the face of possibilistic risk is defined and the equivalence between the prudence condition and a positive possibilistic precautionary saving is proved. Some relations between possibilistic risk aversion, prudence and possibilistic precautionary saving were established.**

***Keywords* — Possibility theory, Precautionary saving, Prudence**

I. Introduction

THE effect of risk on saving was studied for the first time by Leland [1], Sandmo [2] and Drèze and Modigliani [3]. They showed that if the third derivative of the utility function is positive, then the precautionary saving is positive. Kimball introduced in [4] the notion of ″prudence″ and established its relation with optimal saving.

This paper aims to approach optimal saving and prudence in the context of Zadeh's possibility theory [5]. The first contribution of this paper is a model of optimal saving, similar to the one in [4] or [6], p. 95. The notion of possibilistic precautionary saving (associated with a weighting function f, a fuzzy number A representing the risk and a utility function representing the consumer) is introduced and necessary and sufficient conditions for its positivity are established. The second contribution is the definition of the notion of prudence in possibilistic sense and its characterization in terms of possibilistic optimal saving. The third contribution refers to some relations between the degree of absolute prudence [4], possibilistic risk aversion [7] and possibilistic precautionary saving. Among others, the possibilistic precautionary premium is defined as a possibilistic measure of precautionary motive.

This notion is analogous to (probabilistic) precautionary premium of [4].

We will survey the content of the paper. In Section 2 are recalled, according to [8], [9], [10] the definition of fuzzy numbers and some associated indicators: possibilistic expected utility, possibilistic expected value and possibilistic variance. The equivalence between the concavity (resp. convexity) of a continuous utility function and a possibilistic Jensen-type inequality is proved.

In Section 3 the possibilistic two-period model of precautionary saving is studied. The consumer is represented by two utility functions u and v and the risk, present in the second period, is described by a fuzzy number. The expected lifetime utility of the model is defined with the help of the notion of possibilistic expected utility. The main introduced notion is possibilistic precautionary saving. It measures the changes on optimal saving produced by the presence of risk in the second period. If this indicator has a positive value then by adding the risk the consumer will choose a greater level of optimal saving. The main result of the section characterizes the positivity of possibilistic precautionary saving by the condition $v''' > 0$. One also proves an approximate calculation formula of possibilistic precautionary saving.

In Section 4 the notion of prudence of an agent in the face of risk situation is described by a fuzzy number. The definition of this notion follows the line of [11], [12], where we find a ″formal″ presentation of probabilistic prudence. The main result of the section is a theorem which characterizes possibilistic prudence in terms of the previously studied optimal saving model.

Section 5 begins by recalling the Arrow-Pratt index [13], [14], the degree of absolute prudence [4] and posibilistic risk premium [7]. A result of the section characterizes the property of possibilistic risk premium to be decreasing in wealth by the comparison between prudence and absolute risk aversion (prudence is larger than absolute risk aversion). Then the notion of possibilistic precautionary premium is introduced and some of its properties which establish relations between prudence, possibilistic risk aversion and possibilistic precautionary saving are proved.

The paper ends with a section of concluding remarks.

II. Possibilistic Expected Utility

Fuzzy numbers are the most studied class of possibility distributions [10]. Their indicators – the expected value and variance represent the main instrument in the possibilistic study of risk phenomena [7], [9].

In this section we will define the fuzzy numbers and their indicators and we will prove a characterization theorem of convex (resp. concave) functions by possibilistic Jensen-type inequalities.

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Let X be a non-empty set. A fuzzy subset of X (shortly, fuzzy set) is a function A:X→[0,1]. A fuzzy set A is normal if A(x)=1 for some x∈X. The support of A is defined by supp(A)={x∈**R**|A(x)>0}.

Assume X=**R**. For γ∈[0,1], the γ-level set $[A]^\gamma$ is defined by

$$[A]^\gamma = \begin{cases} \{x \in R \mid A(x) \geq \gamma \ if \ \gamma > 0 \\ cl(\sup p(A)) \ if \ \gamma = 0 \end{cases}$$

(cl(supp(A)) is the topological closure of supp(A).)

The fuzzy set A is fuzzy convex if $[A]^\gamma$ is a convex subset of **R** for all γ∈[0,1]. A fuzzy set A of **R** is a *fuzzy number* if it is normal, fuzzy convex, continuous and with bounded support. If A, B are fuzzy numbers and λ∈**R** then the fuzzy numbers A+B and λA are defined by

$$(A+B)(x) = \sup_{y+z=x} \min(A(y), B(z))$$

$$(\lambda A)(x) = \sup_{\lambda y = x} A(y)$$

A non-negative and monotone increasing function f:[0,1]→**R** is a *weighting function* if it satisfies the normality condition $\int_0^1 f(\gamma)d\gamma = 1$.

Let f be a weighting function and u:R→R a continuous utility function. Assume that A is a fuzzy number whose level sets have the form $[A]^\gamma = [a_1(\gamma), a_2(\gamma)]$ for any γ∈[0,1].

The possibilistic expected utility E(f,u(A)) is defined by:

$$E(f, u(A)) = \frac{1}{2}\int_0^1 [u(a_1(\gamma)) + u(a_2(\gamma))] f(\gamma) d\gamma \quad (1)$$

If u is the identity function of **R** then E(f, u(A)) is the possibilistic expected value [9]:

$$E(f, A) = \frac{1}{2}\int_0^1 [a_1(\gamma) + a_2(\gamma)] f(\gamma) d\gamma \quad (2)$$

If $u(x) = (x - E(f, A))^2$ for any x∈**R** then E(f,u(A)) is the possibilistic variance [9]:

$$Var(f, A) = \frac{1}{2}\int_0^1 [(a_1(\gamma) - E(f, A))^2 +$$

$$+ (a_2(\gamma) - E(f, A))^2] f(\gamma) d\gamma \quad (3)$$

When f(γ)=2γ, γ∈[0,1], E(f,A) and Var(f,A) are the notions introduced by Carlsson and Fullér in [8].

Proposition 1. [7] Let g, h be two utility functions and a, b∈**R**. If u=ag+bh then E(f,u(A))=aE(f,g(A))+bE(f,h(A)).

Lemma 1. [15] Let u:**R**→**R** be a continuous utility function. The following are equivalent:

a) u is concave;

b) For any a, b∈**R**, $\frac{u(a)+u(b)}{2} \leq u(\frac{a+b}{2})$.

Proposition 2. If u is a continuous utility function then the following are equivalent:

(i) u is concave;

(ii) E(f,u(A))≤u(E(f,A)) for any fuzzy number A.

Proof. (i) ⇒(ii) Let A be a fuzzy number such that $[A]^\gamma = [a_1(\gamma), a_2(\gamma)]$ for γ∈[0,1]. Since u is concave, the following inequality holds:

$$\frac{u(a_1(\gamma)) + u(a_2(\gamma))}{2} \leq u(\frac{a_1(\gamma) + a_2(\gamma)}{2})$$

Taking into account that f≥0 and applying Jensen inequality it follows:

$$E(f, u(A)) = \int_0^1 \frac{u(a_1(\gamma)) + u(a_2(\gamma))}{2} f(\gamma) d\gamma \leq$$

$$\leq \int_0^1 u(\frac{a_1(\gamma) + a_2(\gamma)}{2}) f(\gamma) d\gamma$$

$$\leq u(\int_0^1 \frac{a_1(\gamma) + a_2(\gamma)}{2} f(\gamma) d\gamma) = u(E(f, A))$$

(ii)⇒(i) Let a, b∈**R**, a<b. We consider the fuzzy number A for which $a_1(\gamma) = a$ and $a_2(\gamma) = b$ for any γ∈[0,1]. Then $E(f, u(A)) = \frac{u(a)+u(b)}{2}$ and $u(E(f, A)) = u(\frac{a+b}{2})$.

By hypothesis, we will have $\frac{u(a)+u(b)}{2} \leq u(\frac{a+b}{2})$. This inequality holds for any a, b∈**R** and u is continuous. By Lemma 1, it follows that u is concave. □

Corollary 1. If u is a continuous utility function then the following are equivalent:

a) u is convex;

b) u(E(f,A))≤E(f,u(A)) for any fuzzy number A.

The following result appears implicitly in the proof of Proposition 4.4.2 of [7].

Proposition 3. If u is a utility function of class C^2 then:

$$E(f, u(A)) \approx u(E(f, A)) + \frac{1}{2} u''(E(f, A)) Var(f, A)$$

III. A Possibilistic Model of Precautionary Saving

In this section we define a notion of precautionary saving in the framework of an optimal saving possibilistic model. The positivity of precautionary saving shows that the presence of risk increases the level of optimal saving. Intuitively this points out that the agent is ″prudent″ in the face of possibilistic risk. The main result of the section characterizes this ″prudence in an intuitive sense″ by the positivity of the third derivative of one of consumer's utility functions.

The probabilistic two-period model of precautionary saving from [6], p. 65 is characterized by the following data:

- u(y) and v(y) are the utility functions of the consumer for period 0, resp. 1
- for period 0 there exists a sure income y_0 and for period 1 an uncertain income given by a random variable $\tilde{y}$
- x is the level of saving for period 0

Assume that u, v have the class C^2 and $u' > 0$, $v' > 0$, $u'' < 0$, $v'' < 0$. The expected lifetime utility of the model is:

$$V(s) = u(y_0 - s) + M(v((1+r)s + \tilde{y})) \quad (4)$$

where r is the rate of interest for saving.

The consumer's problem is to choose that value of s for which the maximum of V(s) is attained.

The possibilistic model of optimal saving that we are going to build further starts from the same data, except for the fact that $\tilde{y}$ will be replaced by a fuzzy number.

We fix a weighting function f and a fuzzy number A whose level sets are $[A]^\gamma = [a_1(\gamma), a_2(\gamma)]$ for $\gamma \in [0,1]$.

The (possibilistic) expected lifetime utility W(s) of our model will be defined using the notions of possibilistic expected utility from the previous section.

$$W(s) = u(y_0 - s) + E(f, v((1+r)s + A)) \quad (5)$$

The relation (5) can be written:

$$W(s) = u(y_0 - s) + \frac{1}{2}\int_0^1 [v((1+r)s + a_1(\gamma)) + v((1+r)s + a_2(\gamma))] f(\gamma) d\gamma \quad (6)$$

By derivation, from (6) one obtains:

$$W'(s) = -u'(y_0 - s) + \frac{1+r}{2}\int_0^1 [v'((1+r)s + a_1(\gamma)) + v'((1+r)s + a_2(\gamma))] f(\gamma) d\gamma \quad (7)$$

which can be written:

$$W'(s) = -u'(y_0 - s) + (1+r)E(f, v'((1+r)s + A)) \quad (8)$$

Deriving it one more time it follows

$$W''(s) = u''(y_0 - s) + \frac{(1+r)^2}{2}\int_0^1 [v''((1+r)s + a_1(\gamma)) + v''((1+r)s + a_2(\gamma))] f(\gamma) d\gamma \quad (9)$$

One considers the following optimization problem:

$$\max_s W(s) \quad (10)$$

Proposition 4. (i) W is a strictly concave function.
(ii) The optimal solution $s^* = s^*(A)$ of problem (10) is given by $W'(s^*) = 0$.

Proof. (i) By hypothesis, $u'' < 0$, $v'' < 0$, thus by (9) it follows $W''(s) < 0$ for any $s \in \mathbf{R}$.

(ii) follows from (i). □

By Proposition 4 (ii) and (8), it follows that the optimal solution s^* is determined by the following equality:

$$u'(y_0 - s^*) = (1+r)E(f, v'((1+r)s^* + A)) \quad (11)$$

Let h:$\mathbf{R} \to \mathbf{R}$ be a function of class C^2. If A is a fuzzy number then we denote

$$\Gamma_A(h) = h(E(f,A)) + \frac{h'(E(f,A))}{2} Var(f,A)$$

Proposition 5. The optimal solution s^* of problem (10) has the approximate value:

$$s^* \approx \frac{u'(y_0) - (1+r)\Gamma_A(v')}{u''(y_0) + (1+r)^2 \Gamma_A(v'')}$$

Proof. Applying the first order Taylor formula one has:

$$u'(y_0 - s^*) \approx u'(y_0) - s^* u''(y_0) \quad (12)$$

By Proposition 3

$$E(f, v'((1+r)s^* + A)) \approx v'((1+r)s^* + E(f,A)) + \frac{1}{2} v''((1+r)s^* + E(f,A)) Var(f,A) \quad (13)$$

Applying again the first order Taylor formula it follows

$$v'((1+r)s^* + E(f,A)) \approx v'(E(f,A)) + (1+r)s^* v''(E(f,A))$$

$$v''((1+r)s^* + E(f,A)) \approx v''(E(f,A)) + (1+r)s^* v'''(E(f,A))$$

Replacing in (13) it follows:

$$E(f, v'((1+r)s^* + A)) \approx v'(E(f,A)) + (1+r)s^* v''(E(f,A)) + \frac{1}{2}[v''(E(f,A)) + (1+r)s^* v'''(E(f,A))] Var(f,A) = [v'(E(f,A)) + \frac{v''(E(f,A))}{2} Var(f,A)] + (1+r)s^*[v''(E(f,A)) + \frac{v'''(E(f,A))}{2} Var(f,A)]$$

from where one obtains:

$$E(f, v'((1+r)s^* + A)) \approx \Gamma_A(v') + (1+r)s^* \Gamma_A(v'') \quad (14)$$

From (11), (13), (14) we obtain

$$u'(y_0) - s^* u''(y_0) \approx (1+r)\Gamma_A(v') + (1+r)^2 s^* \Gamma_A(v'')$$

From where the following approximate value of s^* follows:

$$s^* \approx \frac{u'(y_0) - (1+r)\Gamma_A(v')}{u''(y_0) + (1+r)^2 \Gamma_A(v'')}$$ □

We consider now the optimal saving model in which in period 1 we don't have uncertainty any more: the uncertain income A is replaced by the sure income E(f,A). The lifetime utility of the model is:

$$W_1(x) = u(y_0 - s) + v((1+r)s + E(f,A)) \quad (15)$$

and the optimization problem becomes:

$$\max_s W_1(s) = W_1(s_1^*) \quad (16)$$

In this case one has

$$W_1'(s) = -u'(y_0 - s) + (1+r)v'((1+r)s + E(f,A)) \quad (17)$$

The optimal solution $s_1^* = s_1^*(E(f,A))$ of problem (16) is given by $W_1'(s^*) = 0$, which, by (17), is written:

$$u'(y_0 - s_1^*) = (1+r)v'((1+r)s_1^* + E(f,A)) \quad (18)$$

The difference $s^* - s_1^*$ will be called *possibilistic precautionary saving* (associated with y_0, r and A). This indicator measures the way the presence of the possibilistic risk A causes changes in consumer's decision to establish the optimal saving.

The following proposition is the main result on our optimal saving model. The key-element of its proof is the application of Proposition 2.

Proposition 6. The following assertions are equivalent:

(i) $s^*(A) - s_1^*(A) \geq 0$ for any fuzzy number A;

(ii) $v'''(x) \geq 0$ for any x∈**R**.

Proof. Let A be a fuzzy number. From (17) and (11) one obtains, by denoting $s^* = s^*(A)$:

$$W_1'(s^*) = -u'(y_0 - s^*) + (1+r)v'((1+r)s^* + E(f,A))$$

$$= (1+r)[v'((1+r)s^* + E(f,A)) -$$

$$- E(f, v'((1+r)s^* + A))]$$

Since W_1' is a strictly decreasing function one has

$s^*(A) \geq s_1^*(A)$ iff

$$W_1'(s^*(A)) \leq W_1'(s_1^*(A)) = 0$$

Taking into account the value of $W_1'(s^*)$ computed above one obtains:

$s^*(A) \geq s_1^*(A)$

iff

$$v'(E(f,(1+r)s^*(A) + A)) \leq E(f, v'((1+r)s^*(A) + A))$$

The previous inequality holds for any fuzzy number A, thus, by Corollary 1, the following equivalences follow:

- $s^*(A) \geq s_1^*(A)$ for any fuzzy number A
- v' is convex
- $v'''(x) \geq 0$ for any x∈**R**.

Condition (i) of Proposition 6 (=the positivity of possibilistic precautionary saving) expresses the fact that the presence of risk leads to the increase of optimal saving, and condition (ii) is the well-known property of ″prudence″ introduced by Kimball in [4]. Since condition (ii) is present both in Kimball's result and in Proposition 6, we conclude that the positivity of possibilistic precautionary saving is equivalent with the positivity of probabilistic precautionary saving.

Example 1. We consider the possibilistic optimal saving model with the following utility functions:

$u(y) = v(y) = -e^{-y}$ for y∈**R**.

We remark that $u'(y) = v'(y) = e^{-y}$, $u''(y) = v''(y) = -e^{-y}$ for any y∈**R**.

Let A be a fuzzy number and f a weighting function. Then

$$\Gamma_A(v') = e^{-E(f,A)} - \frac{1}{2}e^{-E(f,A)}Var(f,A)$$

$$\Gamma_A(v'') = -e^{-E(f,A)} + \frac{1}{2}e^{-E(f,A)}Var(f,A)$$

By Proposition 5, the optimal solution of problem (10) will have the approximate value:

$$s^* \approx \frac{u'(y_0) - (1+r)\Gamma_A(v')}{u''(y_0) + (1+r)^2\Gamma_A(v'')}$$

$$= \frac{e^{-y_0} - (1+r)e^{-E(f,A)}[1 - \frac{1}{2}Var(f,A)]}{-e^{-y_0} + (1+r)^2 e^{-E(f,A)}[-1 + \frac{1}{2}Var(f,A)]}$$

The approximate value of s^* can be written:

$$s^* \approx -\frac{1 - (1+r)\theta(y_0,A)}{1 + (1+r)^2\theta(y_0,A)}$$

where

$$\theta(y_0, A) = e^{y_0 - E(f,A)}[1 - \frac{1}{2}Var(f,A)]$$

If we replace A with the fuzzy point E(f,A) it follows:

$$\theta(y_0, E(f,A)) = e^{y_0 - E(f,A)}$$

since $Var(f, E(f,A)) = 0$. In this case we obtain an approximate value of the optimal solution of problem (10):

$$s_1^* \approx -\frac{1 - (1+r)\theta(y_0, E(f,A))}{1 + (1+r)^2\theta(y_0, E(f,A))}$$

$$= -\frac{1 - (1+r)e^{y_0 - E(f,A)}}{1 + (1+r)^2 e^{y_0 - E(f,A)}}$$

IV. Possibilistic Prudence

In this section we will define the meaning that an agent is prudent in the face of risk modeled by a fuzzy number. This definition is inspired by the concept of prudence in possibilistic sense as it has been defined in [12], [11]. Using the results from the previous section we will find an equivalent formulation of possibilistic prudence in terms of precautionary saving.

Consider an agent with the utility function u of class C^2 with $u' > 0$, $u'' < 0$ and f a weighting function. If X is a random variable then M(X) is its expected value and M(u(X)) is the expected utility associated with u and X.

The probabilistic utility premium w(x, X, u) associated with the real number x, the random variable X and u was introduced by Friedman and Savage in [16]:

$$w(x,X,u)=u(x)-M(u(x+X)) \quad (19)$$

By [17], the probabilistic utility premium w(x, X, u) measures ″the degree of pain associated with facing the risk X, where pain is measured by the loss in the expected utility from adding the risk X to wealth x″.

Similarly, we will define the possibilistic utility premium w(x, A, u) associated with $x\in\mathbf{R}$, the fuzzy number A and the utility function u by

$$w(x,A,u)=u(x)-E(f,u(x+X)) \quad (20)$$

Assume that the level sets of the fuzzy number A are $[A]^{\gamma}=[a_1(\gamma),a_2(\gamma)]$ for any $\gamma\in[0,1]$. Then (20) is written:

$$w(x,A,u)=u(x)-\frac{1}{2}\int_0^1 u(x+a_1(\gamma))+$$
$$+u(x+a_2(\gamma))]f(\gamma)d\gamma \quad (21)$$

We recall from [11], [12] what means that the agent is probabilistically prudent.

Let x be the initial wealth, k a positive constant and X a random variable with M(X)=0. We denote

$$S(x,k,X,u)=u(x-k)+M(u(x+X))-u(x)-$$
$$-M(u(x-k+X)) \quad (22)$$

One notices that $S(x,k,X,u)=w(x-k,X,u)$ - $-w(x,X,u)$

$S(x,k,X,u)$ is called in [17] the prudence utility premium and it is interpreted as measuring ″the increase in pain of facing the risk X in the presence of a sure loss k>0″.

By [11], [12], we say that the agent u is probabilistically prudent if $S(x,k,X,u)\geq 0$ for any triple (x,k,X) as above.

The above discussion is the starting point in defining the possibilistic prudence.

If x is the initial wealth, k a positive constant and A a fuzzy number with E(f,A)=0 then we denote

$$S(x,k,A,u)=u(x-k)+E(f,u(x+A))-u(x)\text{ -}$$
$$-E(f,u(x-k+A)) \quad (23)$$

$S(x,k,A,u)$ will be called the possibilistic prudence utility premium. It has a similar interpretation with the probabilistic prudence utility premium $S(x,k,X,u)$, but we have the possibilistic risk A instead of probabilistic risk X.

One sees immediately that

$$S(x,k,A,u)=w(x-k,A,u)-w(x,A,u) \quad (24)$$

Definition 1. The agent u is possibilistically prudent if $S(x,k,A,u)\geq 0$ for any triple (x,k,A) with the above significance.

Remark 1. According to (24), the agent is possibilistically prudent iff the possibilistic utility premium w(x,A,u) is decreasing in x.

Proposition 7. Assume that the utility function u has the class C^3 and $u'>0$, $u''<0$. Then the following are equivalent;

(i)The agent u is possibilistically prudent;

(ii) $u'''(x)\geq 0$ for any $x\in\mathbf{R}$.

Proof. Deriving (21) w.r.t. x we obtain

$$w'(x,A,u)=u'(x)-\frac{1}{2}\int_0^1[u'(x+a_1(\gamma))+$$
$$+u'(x+a_2(\gamma))]f(\gamma)d\gamma$$
$$=u'(x)-E(f,u'(x+A))$$

From the previous inequality and taking into account Remark 1 and Corollary 1 the equivalence of the following assertions follows:

- the agent u is possibilistically prudent
- $w'(x,A,u)\leq 0$ for all x and A
- $u'(x)\leq E(f,u'(x+A))$ for all x and A
- $u'(E(f,x+A))\leq E(f,u'(x+A))$ for all x and A
- u' is convex
- $u'''\geq 0$ □

We go back now to the possibilistic precautionary saving model from Section 3 (u(y) and v(y) are the utility functions of the consumer for period 0, resp. 1).

Theorem 1. Under the conditions of Section 3 the following assertions are equivalent:

(a) $s^*(A)-s_1^*(A)\geq 0$ for any fuzzy number A

(b) $v'''(x)\geq 0$ for any $x\in\mathbf{R}$

(c) The agent v is possibilistically prudent.

Proof. (a)⇔(b) By Proposition 6.

(b)⇔(c) By Proposition 7. □

Remark 2. The above theorem provides a more intuitive meaning to the notion of possibilistic prudence formally introduced by Definition 1. Indeed, by the equivalence (a)⇔(c) it follows that the agent v is possibilistically prudent iff in the presence of risk he chooses a higher level of optimal saving.

Remark 3. In the optimal saving model of Section 3, the consumer is represented by the pair of utility functions (u,v). As the risk may appear only in period 1 (when the consumer ‘s behavior is described by v), the prudence of consumer (u,v) in the face of risk coincides with v’s prudence in the face of risk. Therefore, under condition (c) of Theorem 1, we deal with the prudence of consumer (u, v).

V. Prudence and Possibilistic Risk Aversion

Following the line of Kimball from [4], in this section we will investigate the relation between prudence and possibilistic risk aversion, issue treated in [7]. Both topics describe two attitudes of an agent in the face of risk. By defining possibilistic precautionary premium as a case of possibilistic risk premium [7], the results of the theory of possibilistic risk aversion are transferred to possibilistic prudence.

We consider an agent with the utility function u of class C^2 and $u' > 0$, $u'' < 0$. The *Arrow-Pratt index* r_u is defined by [13], [14]:

$$r_u(x) = -\frac{u''(x)}{u'(x)}, \ x \in \mathbf{R}. \quad (25)$$

If u has the class C^3 then the *degree of absolute prudence* P_u was defined by Kimball in [4]:

$$P_u(x) = -\frac{u'''(x)}{u''(x)}, \ x \in \mathbf{R}. \quad (26)$$

One notices that $P_u \geq 0$ iff $u''' \geq 0$. If $g = -u'$ then $P_u = r_g$.

In the above mentioned papers, r_u and P_u are indicators for analyzing probabilistic risk.

r_u is a measure of risk aversion and P_u is a measure of the agent's prudence in the face of risk. By [7], the Arrow-Pratt index is an efficient instrument for the study of risk represented by fuzzy numbers.

We fix a weighting function f, a utility function u, a fuzzy number A and a real number x. u represents the agent, A the risk situation and x is the wealth. We define the possibilistic risk premium $\pi(x, A, u)$ as the unique solution of the equation:

$$E(f, u(x+A)) = u(x + E(f, A) - \pi(x, A, u)) \quad (27)$$

In interpretation, the bigger $\pi(x, A, u)$ is, the bigger the agent's risk aversion is.

Proposition 8. [7]

$$\pi(x, A, u) \approx \frac{1}{2} r_u(x + E(f, A)) Var(f, A)$$

Let u_1, u_2 be the utility functions of two agents such that $u_1' > 0$, $u_2' > 0$, $u_1'' < 0$, $u_2'' < 0$. We denote $r_1 = r_{u_1}$, $r_2 = r_{u_2}$.

Proposition 9. [7] The following assertions are equivalent:

(a) $r_1(x) \geq r_2(x)$ for any x∈**R**;

(b) For any x∈**R** and for any fuzzy number A, $\pi(x, A, u_1) \geq \pi(x, A, u_2)$.

The above result is the possibilistic analogue of Pratt theorem [14]. It shows how using the Arrow-Pratt index one can compare the aversions to possibilistic risk of the two agents.

The following proposition establishes a connection between the possibilistic risk aversion and prudence.

Proposition 10. The following assertions are equivalent:

(i) For any fuzzy number A, the possibilistic risk premium $\pi(x, A, u)$ is decreasing in wealth: $x_1 \leq x_2$ implies $\pi(x_2, A, u) \leq \pi(x_1, A, u)$;

(ii) For all x∈**R**, $P_u(x) \geq r_u(x)$ (prudence is larger than risk aversion).

Proof. Let A be a fuzzy number with $[A]^\gamma = [a_1(\gamma), a_2(\gamma)]$, γ∈[0,1]. From (27) it follows:

$$u(x + E(f, A) - \pi(x, A, u)) =$$
$$= \frac{1}{2}\int_0^1 [u(x + a_1(\gamma)) + u(x + a_2(\gamma))] f(\gamma) d\gamma$$

Deriving and applying again (27) for $g = -u'$ one obtains:

$$(1 - \pi'(x, A, u)) u'(x + E(f, A) - \pi(x, A, u)) =$$
$$= -\frac{1}{2}\int_0^1 [g(x + a_1(\gamma)) + g(x + a_2(\gamma))] f(\gamma) d\gamma =$$
$$= -E(f, g(x + A))$$
$$= -g(x + E(f, A) - \pi(x, A, g))$$

From these equalities it follows:

$$\pi'(x, A, u) = \frac{g(x + E(f, A) - \pi(x, A, g)) - g(x + E(f, A) - \pi(x, A, u)}{u'(x + E(f, A) - \pi(x, A, u))}$$

By hypothesis, $u' > 0$ and g is strictly increasing, thus the following assertions are equivalent:

- $\pi(x, A, u)$ is decreasing in x
- For all x, $\pi'(x, A, u) \leq 0$
- For all x, $g(x + E(f, A) - \pi(x, A, g)) \leq$ $\leq g(x + E(f, A) - \pi(x, A, u))$
- For all x, $\pi(x, A, g) \geq \pi(x, A, u)$

By these equivalences and Proposition 9, the following assertions are equivalent:

- For any fuzzy number A, $\pi(x, A, u)$ is decreasing in x
- For any fuzzy number A and x∈**R**, $\pi(x, A, g) \geq \pi(x, A, u)$
- For any x∈**R**, $r_g(x) \geq r_u(x)$

Since $P_u(x) = r_g(x)$, the equivalence of assertions (i) and (ii) follows. □

The (probabilistic) *precautionary premium* was introduced in [4] as ″a measure of the strength of precautionary saving motive″. We define now a similar notion in a possibilistic context.

Let v be a utility function of class C^3 with $v' > 0$, $v'' < 0$ and $v''' > 0$. The *possibilistic precautionary premium* $\phi(x, A, v)$ associated with wealth x, a fuzzy number A representing the risk and the utility function v is the unique solution of the equation:

$$E(f, v'(x + A)) = v'(x + E(f, A) - \phi(x, A, v)) \quad (28)$$

We returned to the model of precautionary saving of Section

3, assuming that v has the class C^3 and $v' > 0$, $v'' < 0$, $v''' > 0$. By the optimum condition (11) of Section 3 and equation (28), it follows:

$$u'(y_0 - s^*) =$$
$$= (1+r)E(f, v'((1+r)s^* + A))$$
$$= (1+r)v'((1+r)s^* + E(f,A) - \phi((1+r)s^*, A, v))$$

We consider the case r=0 and u=v. Then

$$u'(y_0 - s^*) = u'(s^* + E(f,A) - \phi(s^*, A, v))$$

from where, taking into account that u' is injective, it follows:

$$s^* = \frac{1}{2}(y_0 + \phi(s^*, A, v) - E(f,A)) \qquad (29)$$

Remark 4. The results of Section 4 connect possibilistic prudence and possibilistic precautionary saving. The size of a consumer's prudence is evaluated by the level of optimal saving s^*: the bigger s^* is, the more prudent the consumer is. Relation (29) between s^* and $\phi(s^*, A, v)$ shows that the possibilistic precautionary premium is an indicator of the agent's prudence.

One notices that $\phi(x, A, v) = \pi(x, A, -v')$ therefore we can apply to $\phi(x, A, v)$ all the results valid for possibilistic risk premium. In particular, Propositions 8, 9, 10 lead to

Proposition 11.

$$\phi(x, A, v) \approx \frac{1}{2} P_v(x + E(f,A)) Var(f, A)$$

Proposition 12. Let v_1, v_2 be two utility functions of class C^3 with $v_1' > 0$, $v_2' > 0$, $v_1'' < 0$, $v_2'' < 0$, $v_1''' > 0$, $v_2''' > 0$. The following assertions are equivalent:

(a) $P_{v_1}(x) \geq P_{v_2}(x)$ for any x∈**R**

(b) For any x∈**R** and for any fuzzy number A, $\phi(x, A, v_1) \geq \phi(x, A, v_2)$

Proposition 13. Let v be a utility function of class C^4 with $v' > 0$, $v'' < 0$, $v''' > 0$, $v^{iv} < 0$. The following assertions are equivalent:

(i) For any fuzzy number A, the possibilistic precautionary premium $\phi(x, A, v)$ is decreasing in x;

(ii) $-\frac{v^{iv}(x)}{v'''(x)} \geq -\frac{v'''(x)}{v''(x)}$ for any x∈**R**.

The three propositions from above are possibilistic versions of theorems of Kimball [4]. Proposition 11 provides an approximate calculation formula of possibilistic precautionary premium w.r.t. the index of absolute prudence and the possibilistic indicators associated with a fuzzy number A. The equivalence of conditions (a), (b) of Proposition 12 gives a criterion to compare the prudence of the agents represented by the utility functions v_1, v_2. By [12], $-\frac{v^{iv}(x)}{v'''(x)}$ is called the degree of temperance of the utility function v. As $-\frac{v'''(x)}{v''(x)}$ is the degree of absolute prudence of v, the inequality of condition (ii) of Proposition 13 expresses the fact that temperance is bigger than prudence.

VI. Conclusion

The possibilistic approach of the optimal saving problem is founded on the hypothesis that risk situations are represented by fuzzy numbers, and consumers are described by their utility functions. The formulation of the possibilistic optimal saving problem and the definition of possibilistic prudence use the notion of possibilistic expected utility from [7]. The study of these two topics and their interconnections use the two main possibilistic indicators: expected value and variance [7], [9].

This paper contains the following contributions:

- The characterization of the concavity of continuous utility functions by a possibilistic Jensen-type inequality;
- The definition of the notion of possibilistic precautionary saving and the characterization of its prudence (i. e. the optimal saving increases in the presence of risk) by the condition of positivity of the third derivative of the utility function (= the prudence in the sense of Kimball [4]) ;
- The definition of the notion of possibilistic prudence (following the line of [11], [12]) and its characterization by the positivity of precautionary saving
- The relation between possibilistic risk aversion and prudence;
- The definition of possibilistic precautionary premium as ″strength″ of possibilistic precautionary saving, its approximate calculation and its use to compare the degrees of absolute prudence of two consumers.

We mention a few directions to continue the research of this paper:

- the study of a model of optimal saving and prudence in case of several risk parameters represented by fuzzy numbers;
- the study of optimal saving and prudence for situations with mixed risk parameters: ones represented by random variables, and others by fuzzy numbers;
- the possibilistic analysis of temperance and other higher-order risk attitudes of an agent [18].

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Analysis of Bullying in Cooperative Multi-agent Systems' Communications

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***Abstract* — Cooperative Multi-agent Systems frameworks do not include modules to test communications yet. The proposed framework incorporates robust analysis tools using IDKAnalysis2.0 to evaluate bullying effect in communications. The present work is based on ICARO-T. This platform follows the Adaptive Multi-agent Systems paradigm. Experimentation with ICARO-T includes two deployments: the equitative and the authoritative. Results confirm the usefulness of the analysis tools when exporting to Cooperative Multi-agent Systems that use different configurations. Besides, ICARO-T is provided with new functionality by a set of tools for communication analysis.**

***Keywords*— Analysis, Bullying, Communication, Cooperative Multi-agent Systems, ICARO-T.**

I. Introduction

Cooperative Multi-agent Systems are a type of Multi-agent System (MAS) which main goal concerns the design of complex systems for which the global behavior emerges from the behaviors and interactions of the agents that compose the system. Each agent has an individual goal and a behavior based on a cooperative attitude.

Tools to evaluate communications among agents are relevant to build an efficient architecture in cooperative MAS, in order to fulfill a complete agent-oriented software engineering (AOSE) paradigm. Although this type of tools has been used in non adaptive MAS, like those built under the Ingenias Development Kit (IDK) methodology [1], they have not been applied to a cooperative model.

Communications analysis tools are intended to discover non equal communications among agents, like the ones presents in [2], which identify patterns that appear in a bully scenario:

- bully agents, when they send too many messages.
- mistreated agents, when they received too many messages.
- mistreated-bully agents, when they send and receive too many messages.
- isolated agents, when they neither send nor receive messages.
- regular agents, when they behave correctly because they send and receive messages in a balanced way.

It is desirable to design communications where all agents follow regular patterns. If this situation does not happen, agents may be overloaded and/or overloading with messages, causing the overall system to be suffering of a bullying affect as well. In MAS where agents have different roles depending on their goals, non balanced communication can also appear in a group of agents with the same role. This is the case when there is a bad policy of selection of an agent among several agents of the same type.

Therefore, the bullying effect can appear at three levels:

1) Agent level, when there are agents with non desirable patterns.
2) Type of agent level, when there are types of agents with non desirable patterns.
3) System level, when the system level presents non desirable patterns.

To avoid bullying effect, the designer must handle validation tools which also identify the possible origin of the bullying (e.g., a conversation). With this information, it is possible a re-design of the MAS interactions, towards a MAS a system without bullying. The final consequence of a good design of communications is low response times, and higher Quality of Software (QoS) results, [2], [3].

The framework presented in [4], IDKAnalysis2.0, carries out an analysis of bullying behaviors in communications of MAS built with IDK tool. Its design is based on two modules, so that the second module carries out the validation. This separation males possible the integration of the second module in other MAS architectures. These ones must feed the second module with the logs extracted from the messages exchanged in the conversations among agents. The logs must contain the necessary information to perform the bullying classification.

The contribution of this paper is twofold:

1) To test IDKAnalysis2.0 with a cooperative MAS platform. This will consolidates IDKAnalysis2.0 as an exportable platform for different kinds of MAS, and is a step forward to a new version IDKAnalysis3.0.
2) To complete a cooperative MAS framework with a set of tools that validates the correctness of the design of MAS communications.

This work includes a study of the related work concerning a type of cooperative AMAS in Section 2. Section 3 contains a description of the framework that follows this paradigm,

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ICARO-T. Section 4 includes a full description of the whole architecture composed of ICARO-T and part of IDKAnalysis2.0. Section 5 includes the results of the experimentation using the new platform. And finally, Section 6 contains the conclusions and future work.

II. Related Work

The design of adaptive complex systems based on cooperative MAS and emergence has been studied since the 90s. In this vein, there is a relevant theory, called Adaptive Multi-Agent Systems (AMAS) [5], [6]. The main concept of this theory is to gives local criteria to design agents in order to make possible the emergence of an organization in the system and produce its global function in consequence. The characteristic of adaptation of the system makes possible this function to change and is produced by self-organization of the agents. The cooperative attitude is the main purpose of this self-organization since it guides, locally, the agents in its decision making. The designer task is to define: the agents, the environment (if needed) and the means for interaction; the organization is emerging. This approach contrasts with others where the designer has to specify the organization, like those based on the AGR (Agent, Groups, Roles) model [7], or INGENIAS [8].

The contributions to AMAS paradigm include:

- A methodology to design software for emergent behaviours, called ADELFE [9], which includes operational needs/requirements analysis, analysis and design phases, available on www.irit.fr/ADELFE. It is also a pioneer in considering as well the environment as helping to identify the agents.
- A formalization the AMAS theory, by the use extended automata products [10].
- Experimentations using different scenarios:, STAFF, ABROSE, FORSIC, ANTS, ARCADIA, and so on.

From the above-mentioned state-of the-art, at the time being, there is not a methodology to analyze and debug agent communications for AMAS.

III. ICARO-T Framework

ICARO-T is a representative platform of this cooperative paradigm [11]. ICARO-T is a software infrastructure designed for the development of applications with agent organizations. ICARO-T provides "agent patterns" from which instances of “application agents” can be generated and executed on the nodes of a processor network. Applications are modeled as organizations composed of agents and resources. Table I shows the main differences between ICARO-T and other agents platforms.

ICARO-T paradigm offers the possibility to model MAS cooperation in two ways:

1) A team model following AMAS theory, where task responsibility is assigned on the most suitable cost evaluation to achieve the goal. This assignment is agreed between team nodes by exchanging messages containing these estimations.
2) A hierarchical model where a coordinator assigns the task team members estimations and then assigns the task to the most suitable subordinate based on the cost evaluations sent to him.

This distinction makes possible the analysis of the three levels of communication detailed in Section 1 using the hierarchical model, and only two levels (the agent and system level) using the team model.

TABLE I
Comparison with other Agent Platforms

Feature	ICARO-T	Other Agent Platforms
Representation	Classes in Java	Logic clauses
Communication	Messages/events	Clauses / percepts/ FIPA messages
Paradigm based on	States/Goal processing	BDI Model
Codification	Java patterns	Logic model in Java
Distribution	Transparent	Possible, based on JADE
Support tools	Java tools	Ad-hoc

IV. Solution Architecture

The ICARO-T extended architecture contemplates two modules, following the IDKAnalysis2.0 [4], like Fig. 1 shows.

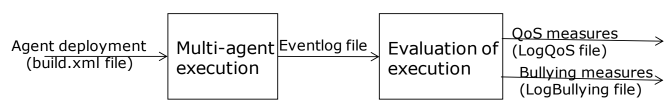

Fig. 1. Block diagram of the IDKAnalysis2.0, extracted from [5].

In our case, the first module is ICARO-T architecture, and the second module is the customization of the evaluation module of IDKAnalysis2.0. Each time a message is received by an agent, an event log is generated in the log event file. The generation of these logs can be extended to other type of events, with more fields, but in this case these logs just contain the basic information for the bullying analysis.

- Name of the agent that receives the message.
- Name of the agent that sends the message.

For both fields, the agent name includes the type of agent it belongs to, so that the bullying effect can also be analyzed at the type of agent level.

There are three parameters for the response time:

- Number of iterations that a task must be executed to calculate the response time.
- The initial task that must be executed to start the response time counting.
- The final task that must be executed to end the response time counting.

For both models (team and hierarchical) these parameters have not been customized because the experimentation case study already provides measurement of the efficiency performance, like the section 5 describes.

The customization of the second module has been done in two ways, each one for each of the two models.

A. Customization of the Evaluation Module for the Team Model

These are the parameters and values customized for this model:

- Role that is suspected to be the Bully in the conversations: *RobotMasterIA*
- Role of that is suspected to be the Mistreated in the conversations: *RobotMasterIA*
- Threshold for the bullying metrics: 1.0

In this case the role is the same for the Bully and the Mistreated, because there is no distinction among the agents, and only the measurements for the agent and system levels are necessary. The name of the agents begins with *RobotMasterIA*

B. Customization for the Evaluation Module for the Hierarchical Model

These are the parameters and values customized for this model:

- Role that is suspected to be the Bully in the conversations*: robotCoordinator*
- Role of that is suspected to be the Mistreated in the conversations: *robotSubordinated*
- Threshold for the bullying metrics: 1.0

In this case, the role to be analyzed as Bully only contains one instance, and corresponds to the coordinator agent; the role suspected to be Mistreated belongs to the subordinate agent type. In this case the three levels of the measurements are going to be taken into account, to detect if the coordinator agent has a bias towards a concrete subordinate agent.

V. EXPERIMENTATION RESULTS

The hardware of the experimentation has been a machine with 2 GHz and 2GB RAM, using 32-bit Windows 7 Professional.

The first stage of the experimentation has been the model used in [12]. The work is part of the research effort undergone in the ROSACE (Robots and Embedded Self-Adaptive Communicating Systems) project available at http://www.irit.fr/Rosace,737. In a simulated fire forest scenario, there are Autonomous Adaptive Vehicles (AAV), who coordinate among themselves for helping potential victims. Agents of the MAS act as the AAV, performing as RobotMaster for the team model, and Robot Coordinator or RobotSubordinate for the hierarchical model.

The communication in the hierarchical model is sent from the coordinator towards the subordinates with two purposes:

1) To request to estimate their cost for achieving the goal.
2) To accept/refuse proposals for assuming the goal.

The communication in the team model is sent among the components, to exchange cost estimations, and decide which member is the best situated to help the victim. Evaluation to assign to a concrete robot the rescue of a concrete victim, is made considering the time needed for helping the victim. In our case, it is useful to test that the communication of both models is not overloaded with too many messages to evaluate the cost of rescue a victim.

A. Experimental parameters

Experimentation has been running using the parameters described in the following subsections:

1) The type of model

As mentioned before, there are two models, the hierarchical model and the team model.

2) The team size and the number of victims

Notation *n*R*m*V represents the configuration for *n* robots and *m* victims. In the present experimentation the running configurations have been:

- 4R6V-4 robots and 6 victims
- 4R16V-4 robots and 16 victims
- 5R16V-5 robots and 16 victims

Fig. 2 shows the distribution of victims and robots (i.e. the AAV's) of a scenario sample for 4 robots and 6 victims configuration.

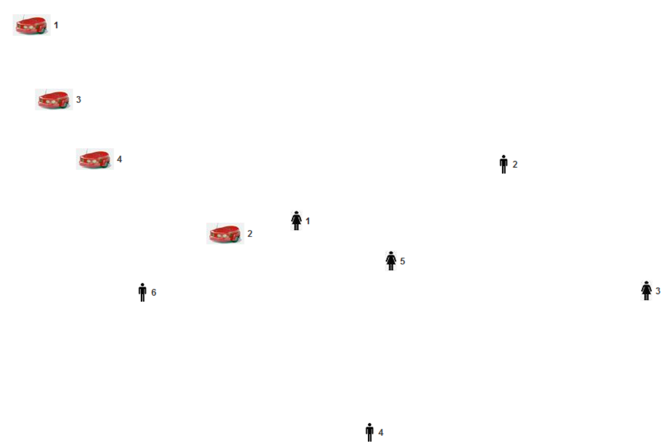

Fig. 2. AAV scenario for 4 robots and 6 victims.

3) The frequency of message

This applies to the time to request the rescue in order to assess the response of the agents when they y are undergoing stressing requests. We have chosen 2 representative values: 80 and 1000 milliseconds

The combination of these three aspects summarizes a total of 12 experimental configurations, as Table II shows.

TABLE II
EXPERIMENTAL CONFIGURATIONS

Type of model	Team and Victims Configuration	Interval time
Hierarchical	4R6V	80
Hierarchical	4R6V	1000
Hierarchical	4R16V	80
Hierarchical	4R16V	1000
Hierarchical	5R16V	80
Hierarchical	5R16V	1000
Team	4R6V	80

Team	4R6V	1000
Team	4R16V	80
Team	4R16V	1000
Team	5R16V	80
Team	5R16V	1000

Fig. 2 Scenario for the victims and robots

Experimental results for all configurations appear in the next subsections.

B. *Bullying results for the hierarchical model*

Bullying results for agents using the mentioned configurations are contained in Table III and IV. The first one shows the values for the metrics at the agent level. BS(Aj) and MS(Aj) values are used to classified the bullying effect of agents related to the agents of the system; in a similar way BR(Aj) and MR(Aj) are related to the agents playing the same role; and CA(Aj) related to ratio between messages received and sent by the agent.

TABLE III
AGENT BULLYING MEASURES FOR THE HIERARCHICAL MODEL

Configuration	Interval time	Agent name	Metric				
			BS(Aj)	MS(Aj)	BR(Aj)	MR(Aj)	CA(Aj)
4R6V	80	RobotCoordinator	5.0	0.0	1.0	0.0	0.0
		RobotSubordinated_1	0.0	1.16	0.0	0.93	1.0
		RobotSubordinated_2	0.0	1.5	0.0	1.2	1.0
		RobotSubordinated_3	0.0	1.16	0.0	0.93	1.0
		RobotSubordinated_4	0.0	1.16	0.0	0.93	1.0
	1000	RobotCoordinator	5.0	0.0	1.0	0.0	0.0
		RobotSubordinated_1	0.0	1.16	0.0	0.93	1.0
		RobotSubordinated_2	0.0	1.5	0.0	1.2	1.0
		RobotSubordinated_3	0.0	1.16	0.0	0.93	1.0
		RobotSubordinated_4	0.0	1.16	0.0	0.93	1.0
4R16V	80	RobotCoordinator	5.0	0.0	1.0	0.0	0.0
		RobotSubordinated_1	0.0	1.18	0.0	0.95	1.0
		RobotSubordinated_2	0.0	1.25	0.0	1.0	1.0
		RobotSubordinated_3	0.0	1.31	0.0	1.05	1.0
		RobotSubordinated_4	0.0	1.25	0.0	1.0	1.0
	1000	RobotCoordinator	5.0	0.0	1.0	0.0	0.0
		RobotSubordinated_1	0.0	1.3	0.0	1.1	1.0
		RobotSubordinated_2	0.0	1.12	0.0	0.9	1.0
		RobotSubordinated_3	0.0	1.25	0.0	1.0	1.0
		RobotSubordinated_4	0.0	1.25	0.0	1.0	1.0
5R16V	80	RobotCoordinator	6.0	0.0	1.0	0.0	0.0
		RobotSubordinated_1	0.0	1.12	0.0	0.93	1.0
		RobotSubordinated_2	0.0	1.25	0.0	1.04	1.0
		RobotSubordinated_3	0.0	1.25	0.0	1.04	1.0
		RobotSubordinated_4	0.0	1.18	0.0	0.98	1.0
		RobotSubordinated_5	0.0	1.18	0.0	0.98	1.0
	1000	RobotCoordinator	6.0	0.0	1.0	0.0	0.0
		RobotSubordinated_1	0.0	1.18	0.0	0.98	1.0
		RobotSubordinated_2	0.0	1.25	0.0	1.04	1.0
		RobotSubordinated_3	0.0	1.18	0.0	0.98	1.0
		RobotSubordinated_4	0.0	1.18	0.0	0.98	1.0
		RobotSubordinated_5	0.0	1.18	0.0	0.98	1.0

Using these values as inputs for the classification rules, like in [2], with standard threshold of 1.00, Table IV shows the class labels for the agents. These results are expected from the type of communication exchanged between RobotCoordinator and RobotSubordinated agents. The first ones must be Bully because they only send messages to the other agents. The second ones must be always be Mistreated because they only receive messages.

TABLE IV
AGENT BULLYING CLASS FOR THE HIERARCHICAL MODEL

Configuration	Interval time	Agent name	Class
4R6V	80	RobotCoordinator	Bully
		RobotSubordinated_1	Mistreated
		RobotSubordinated_2	Mistreated
		RobotSubordinated_3	Mistreated
		RobotSubordinated_4	Mistreated
	1000	RobotCoordinator	Bully
		…	…
5R16V	1000	RobotSubordinated_5	Mistreated

Table V reveals the values for the metrics and class at the RoborSubordinated role level, showing a regular behavior in all configurations. This means that the communication is similar in the agents of this type. RobotCoordinator has not been measured as there is only one agent, and there are not more agents to compare with it.

BR(A_j) MR(A_j) CA(A_j)

TABLE V
ROBOTSUBORDINATED ROLE BULLYING MEASURES AND CLASS FOR THE HIERACHICAL MODEL

Configuration	Interval time	Metric		Class
		BR(R)	MR(R)	
4R6V	80	0.0	1.01	Regular
4R6V	1000	0.0	1.00	Regular
	…	…		
5R16V	1000	0.0	1.00	Regular

Table VI shows the results of the metrics and class at the system level, showing the expected results. In this type of MAS, where there is an agent that sends all messages, and the rest of agents only receive, the expected behavior is of bullying effect, in this case Bully.

TABLE IV
SYSTEM BULLYING MEASURES AND CLASS FOR THE HIERARCHICAL MODEL

Configuration	Interval time	Metric			Class
		BS(S)	MS(S)	CS(S)	
4R6V	80	5.0	1.26	1.56	Bully
	1000	5.0	1.26	1.56	Bully
4R16V	80	5.0	1.25	1.56	Bully
	1000	5.0	1.25	1.56	Bully
5R16V	80	6.0	1.20	1.80	Bully
	1000	6.0	1.20	1.80	Bully

In conclusion, the communication of this MAS has been designed correctly, with a bullying behavior at an agent level, that has been influenced to the system level. Moreover, the communications for the RobotSubordinated agents have been sent in an equal manner among the agents of this type, showing regular patterns in consequence.

C. Bullying results for the team model

Bullying measures for agents of this model have been collected in Table VII. In this case, as all agents belong to the same type, the measures related to the role have not been included, as they do not reveal anything important.

TABLE VII
AGENT BULLYING MEASURES FOR THE TEAM MODEL

Configuration	Interval time	Agent name	Metric		
			BS(Aj)	MS(Aj)	CA(Aj)
4R6V	80	RobotMasterIA_1	1.13	1.08	0.48
		RobotMasterIA_2	0.91	0.91	0.50
		RobotMasterIA_3	1.13	1.11	0.49
		RobotMasterIA_4	0.80	0.88	0.52
	1000	RobotMasterIA_1	0.93	0.96	0.50
		RobotMasterIA_2	1.01	0.98	0.49
		RobotMasterIA_3	1.13	1.15	0.50
		RobotMasterIA_4	0.91	0.89	0.49
4R16V	80	RobotMasterIA_1	1.03	1.61	0.60
		RobotMasterIA_2	1.15	0.00	0.00
		RobotMasterIA_3	0.83	1.18	0.58
		RobotMasterIA_4	0.96	1.19	0.55
	1000	RobotMasterIA_1	0.88	1.00	0.53
		RobotMasterIA_2	0.98	1.02	0.50
		RobotMasterIA_3	1.06	0.95	0.47
		RobotMasterIA_4	1.05	1.00	0.48
5R16V	80	RobotMasterIA_1	1.26	1.18	0.48
		RobotMasterIA_2	0.88	0.97	0.52
		RobotMasterIA_3	0.89	0.93	0.51
		RobotMasterIA_4	0.86	0.98	0.53
		RobotMasterIA_5	1.09	0.92	0.45
	1000	RobotMasterIA_1	1.01	1.11	0.52
		RobotMasterIA_2	0.92	0.94	0.50
		RobotMasterIA_3	1.02	0.91	0.47
		RobotMasterIA_4	1.11	1.06	0.48
		RobotMasterIA_5	0.91	0.96	0.51

Table VIII shows the classification results at the agent level (using the same rules and thresholds as in subsection 5.A) showing that all patterns are regular, except one, which corresponds to RobotMasterIA_2 in the 4R16V configuration for an interval of 80 milliseconds. As this value put more stress than 1000 millisecond, a desyncrhonization delay is produced, due to interruption during the decision of assigning a task to a certain agent. This can cause an imbalanced communication in certain agents, such us this case. Besides that, some results for the configurations using 80 milliseconds are slightly worse that the ones using 1000 millisecond, as the values for the latter show, which are usually closer to 1.00 than the former ones.

In a similar way that in subsection 5.A, results for the team model have been obtained showing regular patterns for the system. The configurations using 80 milliseconds show a slightly worse performance, as explained before. These results have been collected in Table IX.

TABLE VIII
AGENT CLASSIFICATION FOR THE TEAM MODEL

Configuration	Interval time	Agent name	Class label
4R6V	80	RobotMasterIA_1	Regular
		…	…
4R16V	80	RobotMasterIA_1	Regular
		RobotMasterIA_2	Bully
		RobotMasterIA_3	Regular
		…	…

TABLE IX
SYSTEM CLASSIFICATION FOR THE TEAM MODEL

Configuration	Interval time	Metric			Class label
		BS(S)	MS(S)	CS(S)	
4R6V	80	1.02	1.00	1.01	Regular
	1000	1.00	1.00	1.00	…
4R16V	80	1.01	1.36	1.07	
	1000	1.00	1.00	1.00	
5R16V	80	1.02	1.00	1.01	
	1000	1.00	1.00	1.00	Regular

These results are also expected, revealing non bullying communications and an adequate design, in consequence. The value of MS(S) for 4R16V, 80 milliseconds shows a slight deviation from the others, closer to the unit. This is consequence of the deviation in the RobotMasterIA_2 in the agent bullying measures (see Table VII).

VI. CONCLUSIONS AND FUTURE WORK

This work presents a complete framework for a cooperative MAS platform that includes robust tools for communication analysis. These tools may be applied to this type of MAS to discover bullying patterns in communication among agents. ICARO-T platform support this paradigm, concretely the AMAS. The resulted patterns reveal there is a robust design in communication architecture. In the experimentation phase, two different deployments built with ICARO-T have been tested. Although the evaluation at the type level cannot be applied for the team deployment, the two other levels have been tested. In this sense, this research shows that the framework is flexible enough to be integrated with MAS different to IDK, which has the three levels of functionality, and validation. New findings in the metric values show better results for some configuration over the others. The designer can choose the use of the best configurations in executions in terms of equal communications. Therefore, the new framework becomes useful, relevant and consistent to validate communications.

This research opens other perspectives for ICARO-T in particular, and AMAS in general:

- For ICARO-T, future case studies communication can be validated with these tools. Besides, it is planned to validate these case studies with another set of tools, mentioned in section 1, [3].
- For AMAS in general, the possibility to use this framework using analysis tools is open. Besides, there are other analysis tools than can be applied for other purposes, as in

[13] and [14]. As these tools use logs with different kind of information, an ontotology may be parsed to get this information. This can be used by a new version of IDKAnalysis2.0, named IDKAnalysis3.0.

VII. Acknowledgment

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Gamification, Social Networks and Sustainable Environments

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Abstract **— Intelligent environments and ambient intelligence enabled systems provide means to gather rich information from both environments and its users. With the help of such systems, it is possible to foster communities of ambient intelligence systems with community driven knowledge, which is created by individual actions and setups in each of the environments. Such arrangements provides the potential to build systems that promote better practices and more efficient and sustainable environments by promoting the community best examples and engaging users to adopt and develop proactive behaviors to improve their standings in the community. This work aims to use knowledge from communities of intelligent environments to their own benefit. The approach presented in this work uses information from different environments, ranking them according to their sustainability assessment. Recommendations are then computed using similarity and clustering functions ranking users and environments, updating their previous records and launching new recommendations in the process. Gamification concepts are used in order to keep users motivation and engage them actively to produce better results in terms of sustainability.**

Keywords **— Ambient Intelligence, Gamification, Sustainable environments**

I. Introduction

Sustainability is a multi-disciplinary area based in fields such as economy, environment and sociology. These fields of research are interconnected, but humans have different psychological approaches to them. Thus, is necessary to perceive the behaviors behind each multi-disciplinary area. A computational platform to support and promote a sustainable environment, together with an approach to the energetic and economic problems, must take the decisions as smoothly as possible so as not to cause discomfort to the user. This topic triggered several psychological researches [1], [2] and a common conclusion indicates that humans are not always conscious about their behavior [3]. This field, called psychology of sustainable behavior, despite focusing on measurement and understanding the causes of unsustainable behavior, it also tries to guide and supply clues to behavior change. Manning [4], shows some aspects that are necessary to consider promoting and instilling in people sustainable behaviors:

- All behavior is situational, i.e., when the situation or event changes, the behavior changes; even if exists intention to perform a certain behavior, circumstances can make it change;
- There is no unique solution, i.e, people are all different because they have different personalities, living in a specific culture, with distinct individual history;
- Fewer barriers leads to a great effect, i.e., when a person is facing social, physical and psychological obstacles, his attitude tends to flinch; for instance, the lack of knowledge about a procedure leads to a retreat;
- There is no single approach to make an action attempting achievement of sustainability; there are many sustainable possible options that a person can choose.

To overcome these barriers to sustainability, it is suggested the engagement of multiple users in a competitive environment of positive behaviors so that participants have the need to strengthen their knowledge of sustainable actions.

Energy efficiency, which represents optimal use of energy to satisfy the objectives and needs from users, environments and interactions between them, is also an important topic to sustainable environments, although not the only one. According to Herring studies [6], over the last 25 years, the increase in the efficiency of domestic appliances has been nullified by the increase of the use of energy consumption devices. Initial results from energy efficiency policies state that small changes in habits can save up to 10% in home energy consumption [7]. On the other hand, sustainability represents the assurance that environments, users and interaction between them can be endured and, as a consequence, the future replication of the current patterns is not compromised. Both concepts, sustainability and energy efficiency, are not opposed to the use of energy, but they do remind people to be effective on how resources are used and the fact that sustainability concerns the viability of current actions in the present and in the future.

A. Computational Approach to Sustainability

Currently, different approaches to measure and assess sustainability are addressed in the literature. Some focus on an economic perspective while others emphasize environmental or social perspectives [8]. On a computer science perspective, although not being able to directly solve the sustainability

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problem, it can plan and develop solutions to measure and assess sustainability automatically from an environment. This is not due without obtaining information about the environment and its users. The scientific research field of Ambient Intelligence provides a wide spectrum of methodologies to obtain such information in a non-intrusive manner.

The types of sensors used in the environment may be divided into categories to better explain their purpose. Generally, an ambient might be divided by sensors and actuators. Sensors monitor the environment and gather data useful for cognitive and reasoning processes [9]. Actuators take action upon the environment, performing actions such as controlling the temperature, the lightning or other appliances. In terms of sensorization, environment sensors can be divided into sensor that monitor environment or sensor that monitor the user and its activities. This division of sensor classes can also be presented in a different form, taking into consideration the role of the sensor in the environment [10]. In this aspect, sensors might be divided into embedded sensors are installed on objects, context sensors provide information about the environment, or motion sensors.

Envisioning the potentials from computational systems to promote and guarantee sustainability requires all types of sensor classes, as present in some initial project that perform real-time sustainability and energy management [11], [12].

B. *Sustainable Indicators*

Sustainability is a multidisciplinary concept related with the ability to maintain support and endure something at a certain rate or level [13]. The United Nations have defined this concept as meeting the needs of the present without compromising future generation to meet their own needs.

Due to the importance of sustainability different author have defined measures to assess and characterize sustainability. A popular consensus is based on 3 different indicators used to measure the sustainability of a given environment [13]. This approach is based on three different types of indicators, social, economic and environmental with the specific restriction that until all those values are met a system cannot be deemed sustainable. From this perspective sustainability concerns a delicate equilibrium between different indicators which action to optimize one indicator might affect the other two.

The presence of indicators to assess sustainability is an established practice [14],[15], however it does not give any information on how to guarantee or plan sustainability. In fact, indicators only inform about the current status of a system. Common problems with this practice are enumerated in the literature, [15]. The definition of global sustainable indicators, as a means to compare environments, is difficult since environments have different characteristics. Selection and formal definition of indicators is, also, a matter of concern as it has to be agreed by all participants and must have a series of properties, in which the indicators express their relevance. Some authors approach this problem characterizing these properties as dimensions, where some indicators are more important in some dimensions than in others, while monitoring the same object. One other problem is the definition of measuring units and metadata. If not defined accordingly, it may be impossible to compare indicators of the same type. Measuring data makes it possible to obtain an indicator which might have a range of optimal values and a range of non-optimal values.

The use of indicators for sustainability assessment is a common practice across many researchers. Nevertheless, the definition of a sustainable indicator is sometimes difficult and it may differ from environment to environment. In intelligent buildings, there are proposals to build Key Performance Indicators (KPIs) to monitor sustainability and act as sustainable indicators [11]. It has also been identified that indicators are useful at pointing unsustainable practices but not so accurate nor useful to define and guarantee sustainability [16]. Frameworks to evaluate energy efficiency through sustainability in the literature use similar approaches. The goal of energy efficiency was obtained optimizing sustainable indicators which monitor a set of specific energy sources [15]. Industrial environments are also object of energy efficiency projects. In Heilala et al. [11], an industrial AmI is proposed to optimize energy consumption. The main technique used by the AmI system is based on case based reasoning, comparing the data gathered and processed in the AmI with EUP values to assess and diagnose possible inappropriate energy usages. An intelligent decision support model for the identification of intervention needs and further evaluation of energy saving measures in a building is proposed Doukas et al. [7]. The demonstrated concept shows that it is possible to have an intelligent model to perform energy management on a building, combining aspects like ambient climate conditions, investment rates, fuel, and carbon prices, and, also, past experiences.

C. *Gamification and Information Diffusion*

The current and more consensual definition, and one with which we agree and chose to follow, is "the use of game design elements in non-game contexts” [17]. While the concept is recent, the idea from which it is based is not. The notion that the design of the user interface can be built by other design practices has some tradition in HCI (Human-Computer Interaction); during the first peak in the development of computer games, in the early 80s, some authors [18], [19] analyzed game designs in order to create more interesting and pleasing visual interfaces.

The interest in gamification is due to its influence to change people behavior through gamification elements. There are already many studies in regard to gamification, where people use IT to change the behavior of the systems in order to make them more efficient. Still, there is a common trait among them, they are oriented to efficient actions of a system and not to the efficient actions of the user [20]. Changing the former is determining what should be its behavior, while changing the latter means changing their habits, the behaviors that they acquired. In order to tackle this problem, two main concepts can be put in practice: Gamification and Information Diffusion.

In [21], gamification is applied in education where the authors try to take the elements from the games that lead to the engagement and apply them inside the school to the students to keep them motivated. Another example uses a framework that allows users to share their daily actions and tips, review and explore others people actions, and compete with them for the top rank by playing games and puzzles [22]. On another example authors developed a service-oriented and event-oriented architecture framework where all participants communicate via events over a message broker. This system is composed by a set of game rules that define game elements like immediate feedback, rank/levels, time pressure, team building, virtual goods and points (karma points, experience points). Completing game rule generates a reward event for the user over the message broker. There is also an analytical component that may be used to analyze user behavior in order to improve game rules and optimize long-term engagement [23].

As for the second concept, Information Diffusion, this can be applied specifically to social networks. What various studies have proven [24] [25] [26] is that social networks have the potential to diffuse information at a high rate. Besides this point, they can also influence other peers to participate by sharing content. The use of social networks, also mentioned above, has the goal of enhancing the engagement of the users to higher levels by bringing the results to public (respecting user's authorizations) and making each user responsible for his actions at the eyes of the respective network. As we can see through the examples presented, the application of gamification can raise the levels of loyalty of the users and keep them engaged in our objective by making it more enjoyable.

II. Studies on Sustainability Assessment

A. *People Help Energy Savings and Sustainability*

People Help Energy Savings and Sustainability (PHESS) is a project currently being developed at Intelligent Systems Laboratory at University of Minho [15], that was used to conduct preliminary studies in sustainability assessment. It concerns a multi-agent platform (fig. 1) developed to monitor environments as well as its users and perform sustainability assessments, actions and recommendation. The platform establishes an ambient sensorization routine upon the environment, constantly updating sustainable indicators built upon raw data from environment sensors and contextual information.

In order to facilitate management and operational coordination, the system was divided into modules and sub-routines, implemented as software agents acting collaboratively in a multi-agent system. There are a total of 3 modules in the PHESS system:

- data gathering level, responsible for obtaining information about the environment and its user using dedicated hardware and software services available;
- reasoning and contextual level, responsible to use information gathered and update machine learning model, profile users and environment, maintain indicators and perform reasoning tasks upon the information acquired in order to deliver actions plans and recommendation to users;
- acting level, responsible to communicate with environment users, informing user of possible recommendations and controlling actuators in the environment according to user consent and preferences

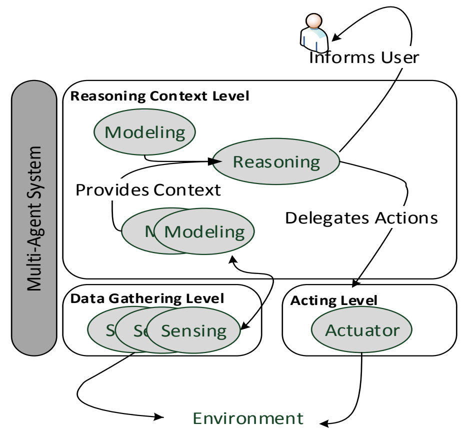

Fig. 4 - PHESS architecture

Sustainability indicators are used to translate the performance of environment and user actions into numeric values that can be used to perform rankings and assessment on recommendation created in the reasoning and contextual level. They represent the current, real time assessment of the environment taking into account historic and real time data. The aim of the platform is not only to assess and identify unsustainable practices but also act with the objective of improving sustainability indicators. For such to happen, user behavior and environment might need to be changed. However, how the change is conducted cannot be determined by sustainability indicators alone.

As a multi-agent system, in the data gathering level in the PHESS platform includes sensing agents responsible for controlling the access and delivery of ambient sensor data model and reason agents in the reason context level. Model agents are responsible to monitor changes in the environment creating models with patterns common pattern and predictors for sensor value. Moreover, model agents may also be responsible for maintaining user or environment sustainable indicators updated. Reason agents use context information to formulate hypothesis in order to create recommendation, optimize environments and behaviors. This knowledge inferred from agents is then used in acting agents in the Acting level in this platform.

The process of using indicators from different environments to create and promote recommendation was developed upon the PHESS to provide familiar recommendations backed up by members of a community. This development is part of the work described in this paper and will be detailed in section 3 with its advantages and disadvantages. Before detailing the recommendation system, an initial explanation about the sustainable indicators and sustainable assessment is necessary to understand the process of creating recommendations.

B. Sustainability Assessment

The sustainable assessment used in PHESS, uses different indicators within each dimension of the sustainability definition. This approach was also used by researchers, which used these indicators to guide strategic options and perform decisions based on the foreseeable impact of such measures [14], [15]. The indicators used in this work are devised to be directly comparable to each other regardless of units or the specificity of each indicator. These indicators represent a ratio between a positive and negative contribution to sustainability and their values are computed in the -1 to 1 range, equation 1. As a consequence, all indicators use the same units of calculation and can be aggregated within each dimension through the use of weighted averages. The use of these indicators is made within each division in the environment and aggregated through average in the environment. Examples of indicator are provided in table I where the variables used as positive and negative values in equation 1 are displayed.

$$\mathrm{Ind}(\mathrm{positive},\mathrm{negative}) = \begin{cases} \frac{\mathrm{positive}}{\mathrm{negative}} - 1 \rightarrow \mathrm{positive} <= \mathrm{negative} \\ 1 - \frac{\mathrm{negative}}{\mathrm{positive}} \rightarrow \mathrm{positive} > \mathrm{negative} \end{cases} \quad (1)$$

In order to deliberate about sustainability performance it is needed to rank solutions rewarding each solution with a sustainable score, equation 2. Indicators within each dimension of sustainability are averaged according to weights defines in each dimension.

TABLE III INDICATOR DEFNITION

	Positive	Negative
Economic	Budget	Consumption
Environmental	Emissions	Estimated Emissions
Social	User inside	User outside

The use of ranking formulas enables the use of fitness functions and distance functions to help calculate distances from one sustainable solution to another. Such approach in explored in section 3, integrated in a case based reasoning algorithm and custom sustainable indicators used to perform a proof-of-concept analysis on the proposed algorithm.

$$S_{index} = \alpha * I_{economic} + \beta * I_{enverinmental} + \gamma * I_{social}$$
$$\alpha + \beta + \gamma = 1 \wedge 0 < \alpha < 1 \wedge 0 < \beta < 1 \wedge 0 < \gamma < 1 \quad (2)$$

Provided with data from the PHESS system it is possible to use such formulas to characterize environments and users according to the same indicator, as well as identify their performance accordingly. As demonstrated in table II and table III, it is evidenced that the performance of each room in a sample environment is affected differently according to how they are used, as well as, user behavior affects their indicator values. These results were obtained using the sample indicators in table I across a sample environment for a period of 3 days.

TABLE IV
SAMPLE RESULTS FROM PHESS SYSTEM

	Social	Economic	Environmental
Kitchen	-0.9011	-0.6859	-0.3263
Bedroom	0.1818	0.9936	0.9024
Living Room	-0.5294	0.1040	-0.2963
Hall	-0.9690	0.9968	0.9954
WC	-0.9900	0.9968	0.9858

TABLE V USER ASSESSMENT

	Social	Economic	Environmental
User 1	-0.004	0.3241	0.281
User 2	0.500	0.927	0.422

C. System analysis

Although the PHESS system is able to extract information from environments and users with significance to perform assessments and recommendation tasks. It was found that the utility of the system depended on how well suggestion are followed and how user adhere to the suggestions being made. Moreover, the use of sustainable indexes is a fast way to categorize action and identify improvement needs but user stimulation to correct such problematic areas is not present. In fact, most systems do not account for the need to motivate user to take action preferring only to make assessments and suggestion to present their findings to users.

There is an opportunity to use computational methods to promote user action on the system, namely with the use of social networks and concepts of gamification. As the improvement of environments and user action is dependable on how user follows recommendations it is of significant importance to improve justification for recommendations and promote them. Over the next section a social recommendation engine is detailed as well as a gamification implementation based on the data retrieved by PHESS.

III. RECOMMENDATION ENGINE

A. Social Recommendation Engine

The recommendation engine is intended to help communities of intelligent systems let users promote practices from different physical environments with high sustainability indexes to others with a recommendation engine. In order to summarize each environment, it was designed a sustainability profile, stating environment and individual room sustainability. Environment indicators are calculated from the use of aggregated individual room indicators, taking advantage of the indicator structure detailed in section 2 indicators for each dimension of sustainability.

The case based reasoning used in this situation uses a two-step process to evaluate and calculate new solutions for the user. As an initial step, the type of environment is contextualized, for instance, sustainable index, number of divisions and room indicators. A second step concerns the recommendation phase, and uses room indicators to obtain the best solution for the planning of energy use and appliance substitution.

The action flow is detailed in figure 2, where from an initial set of grouped environments a target environment can be compared to environments in higher ranked groups.

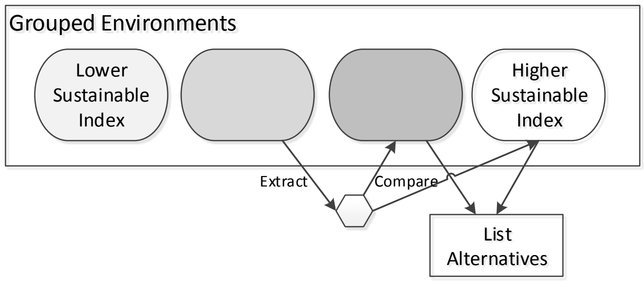

Fig. 5. Social recommendation engine

The initial grouping of environments is made using K-means algorithm on the sustainable index of each environment with a fixed size for number of groups. The retrieval of comparative cases is extracted with the help of similarity functions. In this case, similarity is computed using environments from higher ranked groups and an average Euclidean distance from the distance value, computed for the three sustainability indicators, in every room. This procedure is used taking in consideration the room type, as distances are only calculated for rooms of the same type. The selection of environments favors the longest similarity distance for the value of the indicators in order to help the impact of possible recommendations in the environment. Finally, the list of alternative recommendations is obtained, comparing the room types of the target environment to rooms of the same type in the selecting environment. Any differences found are matched as possible change scenarios, favoring the options taken in the selected environment.

It is useful to remember that sustainable indicators are calculated from data acquired from each environment on a timely basis. The natural consequence is that as time progresses the values of these indicators which might result in environments exchanging the group they were previously.
This dynamic works for the benefit of the system as the selected cases for comparison within each group are changed each time these variations occur enticing environments users to adopt behaviors that do not lead their environment to move to lower ranked groups.

B. *Gamification Implementation*

In this section, the implementation of gamification elements is provided as a means to promote healthy competitions between users and their environment in terms of sustainability and energy efficiency.

Management of user standings and performance is done through web interfaces in which the user is able to monitor the gamification elements devised for him.

The following list details each Gamification element or dynamic implemented. Gamification elements implemented:

- Points, awarded daily according to metrics defined in the system;
- Levels, user standings according to the number
- Achievements, personal objectives launched to user which grant them extra points if followed;
- Leaderboards, visual demonstration of users' rankings according to each other.

These elements were integrated into the developments of PHESS as a mean to promote completion between user with the general objective of increasing sustainable indicators in each environment and user action. As so, the points rewarded in the gamification side are based on the sustainable indicators retrieved by PHESS on a daily basis. Levels group player according to their experience and similar point base. Achievements for each player are based on the recommendations obtained by the social recommendation engine from which suggestions are turned into achievements. Finally leaderboards represent the list of players with their current standings. Communication with the PHESS system is made asynchronously through communication agents responsible for data synchronization. It is expected that by implementing such mechanisms user suggestion acceptance increases, and that user take continuous efforts to improve even when changes rewarding changes are not proposed through the recommendation engine but they are perceived by human intellect.

IV. Results

In order to provide results from the application of each component and their benefits a controlled case study was devised. As such, 4 environments were used with the PHESS system implemented using simulation tools available in the PHESS framework. All environments were assessed using the same group of sample indicators. For the social indicator a positive value is represented by the amount of time spend inside the room whereas the negative value is represented by the time outside. Likewise for economic indicator a positive value is represented by the current budget available and the negative the total amount spent. Regarding the environmental indicator, emissions are derived from the CO_2 emission derived from electricity report for the negative value and emissions avoided as the positive value. Each case is maintained in a profile database and it is updated using the PHESS multi-agent platform. Environment appliance configuration and user behaviors simulate different configurations and user profiles simulating a heterogeneous community. The setup recreated typical environments commonly found, such as apartments with a bedroom, living-room, kitchen, bathroom and a hall connecting all the other rooms. Inside each room, a set of appliances was also defined ranging from lights and computers to ovens and refrigerators with different consumption patterns. The consumption of appliances was defined from their active use and explicit turn on/off actions from user action simulated in the environment.

A. *Recommendation Engine*

In order to test the recommendation system the environments in the test scenario were divided across 3 groups using the algorithm detailed in section III. The initial step requires information about each environment, namely sustainable indexes for each environment and sustainable indicators for each room inside each environment. With information about sustainability on each environment groups was generated resulting with the first group concentrating two of four environments, and one for each of the remaining two groups. Focusing on one of the environment on group with poorer sustainable index, a comparison was made using the environment on the middle group in terms of sustainable index value. For each room possible changes were computed generating a report as defined in table 1 for the living room.

A total of six recommendations were proposed on the target environment in the living room, as seen on table 1, in the kitchen and in the bedroom areas.

TABLE VI RECOMMENDATION SYSTEM REPORT

Appliance	Target Room (Average Consumption)	Best Case (Average Consumption)	Decision
Lights	120W	65W	Change
Computer	49W	55W	Remain
Television	60W	30W	Change
TV Box	55W	-	-

Using the PHESS system it was possible to assess that using recommendations on the living room alone was sufficient to improve the target environment sustainability index.

In fact, iterating the recommendation algorithm one more time it can be found that if recommendations are followed and user behavior remains equal, the environment would be selected for the middle group, thus showing improvement.

Observing the behavior of the community it is possible to assess that the recommendation system is based on the knowledge present within the community.

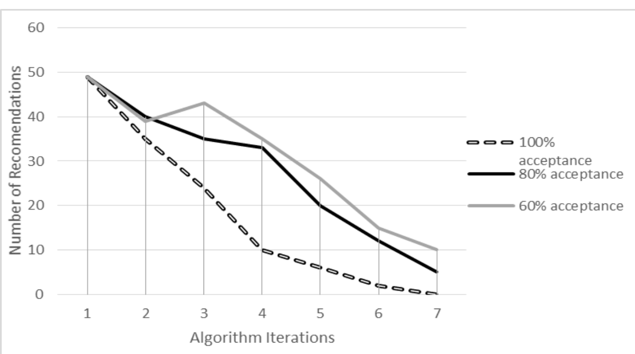

Fig. 6 Number of recommendations by algorithm iteration according to user acceptance

If recommendation are always followed, (100% acceptance) the number of changes proposed converges to zero when environment setups become identical, a point where further improvisation is compromised. Depending on the rate of acceptance of the suggestions this convergence can be slower or faster as showed in figure 3.

B. Gamification

In order to test the dynamics of the gamification elements proposed, tests were simulated using the PHESS system and the gamification system. The points were calculated based on economic sustainable indicator values in the environment and user behavior.

In order to further simulate typical situation inside communities within the four environments the first two were setup with more efficient appliances than the latter two. However, through the different days of use, the first two environment neglected the recommendation proposed as achievements while the others followed them. As it can be seen in figure 4, the gamification elements favor environments were recommendations are followed but the initial efficiency is also taken into consideration as through the first days although recommendations were followed it was not enough to surpass the first two environments.

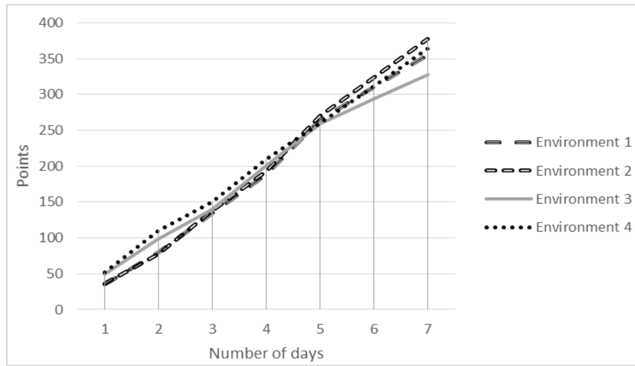

Fig. 7. Environments evolution in the gamification process

C. Improvement of sustainable indexes

Recommendation calculated can be interpreted as using knowledge created within a community to its benefit. The best cases are used as examples to lower ranked cases which provide sense of sympathy from one to another. Also, with this approach, it is not necessary to maintain a database of efficient objects like appliances or lightning. As soon as they appear in the community they tend to be selected for recommendation as part of someone's environment definition.

In order to further promote the adoption of recommendations and foster better behaviors, gamification elements are applied, which in turn, reward sustainable and efficient actions in the community of users and environment. Such rewards are heavily influenced by sustainable indicator devised in the PHESS system, and to climb leaderboards ultimately means to improve such indicators. Additionally, the implementation of recommendations rewards instantaneous points but in order to maintain the benefits such recommendation need to provide long term effects in the system after applied.

Nevertheless, the work detailed needs to catch the user's attention in order to promote its sustainable completion. As there is no safe way to do such thing our implementation is also dependent on user reaction to recommendation and gamification elements to keep improving their standings. But assurance was made to guarantee that in the better gamification results also mean better sustainable environments.

V. CONCLUSION

Ambient intelligence, social networks and gamification present an opportunity to innovate on how to guide and manage resources and human actions making them both more efficient and sustainable. Users share significant amounts of information and by taking advantage of both data gathered by sensorization platform and user input it is possible to build communities and maintain evolutionary recommendation engines that promotes sustainability. The algorithm results and theoretical background support the idea that it possible to use such strategies to drive a social community of user to optimize itself if recommendations are followed. Concepts from gamification also help stimulate competiveness between users resulting in a desire to achieve the global objective with more determination and proactively. Nevertheless, a wide practical validation of results, under a greater set of environments and a user base, is still needed to thoroughly validate findings. This should be accomplished using field tests in a community focused on increasing their sustainability. Furthermore, in order to provide data for the system engine it is needed some specific hardware in order to sense an environment current conditions. Thus, the cost of sensorization and hardware needed should be minimized in large tests as to reduce management costs.

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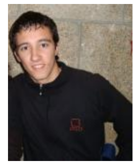

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Application of Hybrid Agents to Smart Energy Management of a Prosumer Node

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Abstract **— We outline a solution to the problem of intelligent control of energy consumption of a smart building system by a *prosumer* planning agent that acts on the base of the knowledge of the system state and of a prediction of future states. Predictions are obtained by using a synthetic model of the system as obtained with a machine learning approach. We present case studies simulations implementing different instantiations of agents that control an air conditioner according to temperature set points dynamically chosen by the user. The agents are able of energy saving while trying to keep indoor temperature within a given comfort interval.**

Key words **— hybrid agents, mas, energy management, prosumer node, hvac, energy efficient buildings**

I. Introduction

Energy management of modern smart buildings requires distributed intelligent control in order to save energy [21].

A smart building with energy management capability is a node which is part of a smart grid of energy; such kind of energy node can be conceived of as a *prosumer*, i.e. producer and consumer of energy in different forms. An energy efficient building already has its passive intrinsic energy efficiency which is embedded by design in its structure and materials, however further improvements in energy efficiency can be achieved by adopting a control methodology inspired to intelligent agents. An intelligent control should be intrinsically dynamic taking into account real-time requirements in response to the building dynamical thermo-physical behavior, considering that it is immersed in a dynamical environment where weather events can change its energy footprint. In other words a proper control that aims at achieving energetic optimality must rely on a detailed model of the thermal behavior of the building areas in the range of observable values of environmental variables.

Such a dynamical model, more complex than the one used during the design of the building, is seldom available and its analytic construction can be highly costly and deemed to be imprecise due to physical complexity of building system and its environment; on the other hand, current techniques in machine learning and model synthesis, when properly fed with sample data, allow an inexpensive run-time prediction of the system behavior much like predictions that an analytical model could give, that can be valuable in planning a heuristical control of the system aimed at specific optimization goals.

In this work we outline a possible implementation of the prosumer agent architecture that is able of a predictive dynamic control of a smart building that, when applied to an air conditioner controller, achieves a better energy efficiency over the usual thermostatic control as implemented in commercial HVACs. The agent is equipped with an intelligent control scheme based on a learning phase that constructs a synthetic model by sampling the system in different environmental and controlled situations. The synthetic model could be used for local forecasting of the system state in order to plan an efficient control.

Our agents architecture includes a perception layer -that incorporates the prosumer forecaster- and a reasoning layer - the prosumer planner. The perception layer has the job of transforming the sensors array signals into abstract predicates, i.e. fluents, that can be handled by the reasoning layer.

The application that we consider falls into the realms of Distributed Intelligent Control Systems that can be described in terms of Complex Event Processing (CEP) [3], where the need for some degree of autonomy is crucial in order to enable components to dynamically respond to ever-changing circumstances while trying to achieve overarching objectives, and properly handle many events. In fact, each definite area of the building -e.g., the dining room, the bathroom, the hall, etc.- can be managed by a hybrid agent which plays the role of the prosumer, in communication with its siblings of the other areas, in order to accomplish the performance goals. Therefore, the energy management of the building can be represented in terms of a Multi-Agent Systems (MAS), where each agent deals with the others in terms of planning and forecasting, as in [2].

The trends extracted from load predictions, energy consumption, and system variables made by the forecaster feed the symbolic interpretation needed for a rule-based logical agent, described in the DALI language. From the planner point of view, this abstraction becomes a fluent in an event calculus context, i.e. events to be handled proactively by the DALI MAS. The latter should also take into account external requirements and user preferences, in order to achieve the

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performance goals, which are defined a priori by the user management.

II. The Prosumer Node

In Fig. 1 an average daily power consumption profile of a prosumer node is shown, where energy load can be obtained by integration. There are times of the day when energy is in surplus, and times were it is in deficiency. An ideal energy manager should level its energy with the given goals, limiting peaks and avoiding surplus periods, and founding its decision on an accurate dynamical behavioral model of the underlying building infrastructure in its environment. A smart building connected to a smart energy grid can be considered at the same time a consumer and a producer of energy. So, a energy prosumer node, as defined by [11], should have local energy sources which are independent from the grid. Usually, these sources include sustainable energy types – e.g. solar thermal and PV, wind, geothermic, etc. – but also conventional fossil fuel based sources, as for instance continuity groups and diesel generators that need to be managed appropriately. The energy prosumer definition should also take into account the local consumption profile and the locally available energy metering tools. An intelligent energy manager should also be present in order to improve the energy efficiency of the prosumer node.

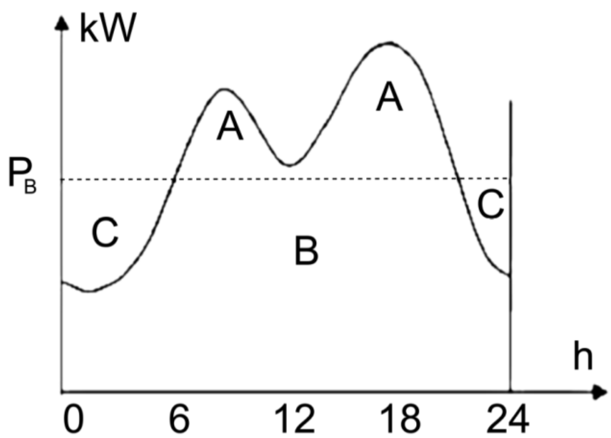

Fig.1: Daily average power consumption of a prosumer nod. PB is the required power level, zone B is the daily load, zone A is the peak demand, zone C is surplus.

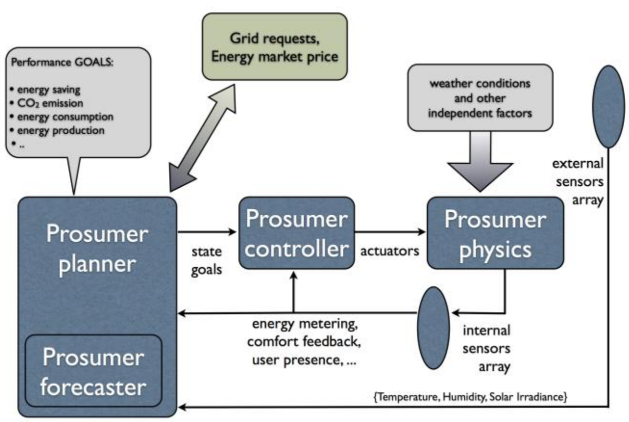

Fig.2: General scheme of the prosumer node reference model.

The intelligent prosumer manager should derive its behavior from the capability to dynamically predict the energy consumption and production given the intrinsic time constant of the building itself – e.g. 15 minutes as a typical thermal inertia of a modern energy efficient building.

In Fig. 2, a general block diagram of a prosumer node is shown. The building energy status is given at each time instant by: external weather conditions, internal user behavior, internal signals and settings in terms of comfort, i.e. internal temperature and reference point. Also the internal sensors set should include what a modern smart building can be equipped with, such as energy load sensors at the power plugs of electrical equipments or at the electrical cabinet for each floor. In this way, a complete energy consumption profile of the building can be obtained at each sampling time. The prosumer controller will then implement a first local control loop that should keep at equilibrium the goals given by the prosumer planner, having an impact on the energy flows by means of the actuators, i.e. heaters, water chillers, air conditioners, windows controls, etc., together with other controllable energy generators or accumulators. The external sensors array should return the state of the most important environmental signals with an impact to the energy profile of the building, i.e. external temperature, solar radiation, humidity, etc.. The resolution and the distribution of the external sensors at which such signals should be sampled depends on the structural configuration of the building. Diffused solar radiation has a major impact on the energy demand of the prosumer node, also can depend on neighborhood buildings for the shading account.

The prosumer planner gets the whole set of signals, internal and external, as well as possible weather models of the area, so as to feed the prosumer forecaster. Then, the prosumer forecaster dynamically produces an estimate of the near future energy requirements (i.e. at the next time sample) of the prosumer node, as well as possibly other environment and system variables, relevant for plan generation and for goal adherence. It can also give the best estimates of internal climate signals, i.e. temperatures, so to that the prosumer planner can reason about comfort evolution and take decisions about the best action to perform.

III. The Energy Management Problem

The energy management problem at a hand could be summarized as in the following. Planning goals could be targeted to possibly conflicting functions such as to minimise energy, cost and CO2 emission, and to keep comfort within a specific interval. Possible conflict between goals might arise due to the different type of resources available like grid, photovoltaic panels, wind rotors or fossil fuel.

Let us define the global goal set such as:

G = {EnergySaving, CostReduction, EmissionReduction, HighestComfort }

These goals are selected by the human energy manager who defines the current general energy policy of the building. Let us consider a prosumer node with a wide range of possible energy actions A, each with a different energy/cost/emission profile, as, for instance:

$$A=\{E_p , E_c , E_a , E_b , E_s \}$$

where subscripts stand for {*p*roduce, *c*onsume, *a*ccumulate, *b*uy, *s*ell} energy. The planner agent might choose an energy generation sequence among feasible ones, as constrained by the given global goals, user preferences, and other local requirements.

Thus, given the input data set I = Ie + Ii as the union of the set of external sensors/variables Ie array and the set of internal sensors/variables array Ii , the prosumer forecaster F can extract relevant variables values from the model f constructed by the machine learning module, behaving as a function F=f(Ie , Ii). The prosumer planner would then generate a plan P as a sequence of possible actions taken from the predefined set A of possible energy related actions, given the prosumer forecaster estimates: P=p(F)=a1(q1)...an(qn), with ai∈A and qi∈Real represents the quantity relative to the action ai. The building energy management goals are processed by the he overall planner, whose results are broadcast, via a FIPA compliant middle layer, to every active prosumer node (supervised by a local agent) managed by the MAS. The agents are in charge of adapting the planner results to the specific situation they are responsible for. As an example, we can consider the case when the global goal at a given time is EnergySaving, and the state goals for the prosumer controller, as example the air conditioner, is the set point at which the thermal zone temperature should be, within the user comfort interval. A domotic[7] technology could embed a planner agent which send control signals to the local controller of a specific area that would co-impose the goal to its local control loop, that is the temperature set point.

The DALI [6] knowledge base with preferences of a prosumer planner agent can be expressed as following:

$$
\begin{aligned}
& \textit{planner\_threshold}_P(\textit{Limit}) : T \;:: \\
& \textit{NEVER unconfortable}(\textit{MyU}) \;:\; \textit{myuser}(\textit{MyU}, \textit{Profile}) \div \\
& \quad \textit{increaseAirConditionerSetPoint}_A(D), D < \textit{Limit} \mid \\
& \quad \textit{decreaseAirConditionerSetPoint}_A(D), D < \textit{Limit} \;::: \\
& \textit{increaseAirConditionerSetPoint}_A > \textit{decreaseAirConditionerSetPoint}_A \\
& \qquad :\text{-}\ \textit{externalTemperatureIrradianceHasSameTrend}. \\
& \textit{increaseAirConditionerSetPoint}_A(D) :< \\
& \quad \textit{userComfortGuaranteed}(\textit{MyU}, \textit{Profile}, \textit{incr}(D)), \textit{plannerHasEnabled} \\
& \textit{decreaseAirConditionerSetPoint}_A(D) :< \\
& \quad \textit{userComfortGuaranteed}(\textit{MyU}, \textit{Profile}, \textit{decr}(D)), \textit{plannerHasEnabled}.
\end{aligned}
$$

This very concise planner agent knowledge base is interpreted as follows. The local planner, relative to a single thermal zone, has three possible actions: increase the temperature set point of the air conditioner, decrease it or standby (hold). There are two preferences, expressed by the rules with connective ‘ > ’. Each rule states that the leftmost action is preferred. The preference rule applies whenever its body (the part after the ‘:-’) holds, and preferences apply to feasible actions. An action is feasible if its preconditions (if any) are verified. Preconditions are expressed by rules with connective ‘:<’. A basic precondition for an action to be feasible is that the action has been enabled by the overall planner (e.g., the planner might not enable temperature decrease if too much energy is being consumed at the moment). If the perception layer, in other words the prosumer forecaster agent, detects that the external environmental signals of temperature and solar irradiance shows the same variation trend, then the planner agent would prefer to increase the temperature set point so to temporally save energy, waiting for a better thermal equilibrium between the building and its environment.

Also, in order to further save energy, it would prefer not doing anything rather than reducing the set point, i.e., decreasing the room temperature, unless user comfort requirements are no more satisfied. In this latter case, being this a precondition to all action, it would definitively reduce the temperature set point until the system is in equilibrium and user comfort requirement is met. An other important pre-condition is the plannerHasEnabled predicate. It allows to configure a hierarchy of planner agents: a global planner agent associated to the whole building and many other sub-agents associated to each thermal zone, or rooms. In this way the knowledge base of the global planner can enable or disable the possible actions of the local planners, depending on global energy reasoning goals, like energy availability or special energy needs.

The above rule is re-evaluated periodically, at a certain (customizable) frequency. This mechanism (which is a generalization of the DALI internal event construct) makes the agent proactive, i.e., capable of autonomously operating on its environment. The frequency will be customized according to the kind of appliances that are being controlled and to the granularity of results that one needs to obtain about temperature and energy consumption.

This kind of multi-agent system based control allows the temperature to be kept within user preferences, overcoming the control scheme of a simple thermostat, which is based only on a kind of “infinite energy supply” hypothesis in order to keep the temperature constant, a policy that is no longer feasible in modern buildings.

IV. Case Study

In a preliminary work [23] we argue that the prosumer forecaster could be implemented with any suitable machine learning approach, where we proposed and experimented using a neural net to predict energy consumption that showed good performance, given the relative smoothness of the response of the system to changes.

In this work we present an experimental simulation of a single instance of a prosumer node as depicted in Fig. 3. In this experiment no real planning is involved yet. Here plans are single actions to achieve a single given goal, so we could collapse the prosumer planner and the prosumer node since the agent acts as a simpler consumption forecaster agent.

As shown in [24] a way to extract information from a large set of measured data is the so-called knowledge discovery in databases (KDD). In this work we applied the KDD method to

[7] home automation

the thermal measurements taken in the laboratory so that the prosumer agent could embeds a model of the environment, room, and HVAC8 system. Such model was constructed using the Eureqa symbolic regression program [18,19] fed with real data sampled in the Roio's HVAC thermal laboratory, as later explained in the experimental setup section. The derived analytical model is capable to give a good estimate of the internal temperature and HVAC electrical consumption, given the external weather condition, as shown in Fig.5.

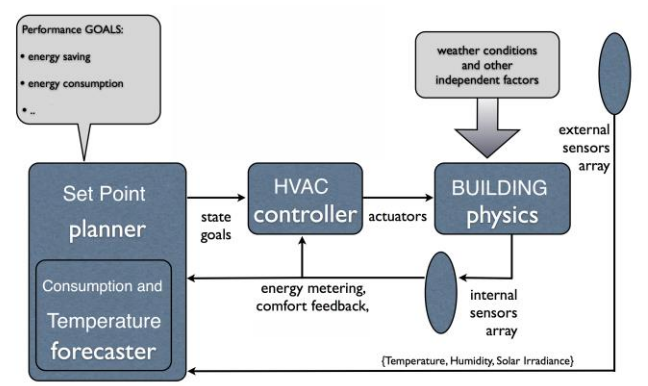

Fig. 3: Simplified prosumer implementation as used in the experimentation. The internal temperature forecaster takes into account also the consumption forecast.

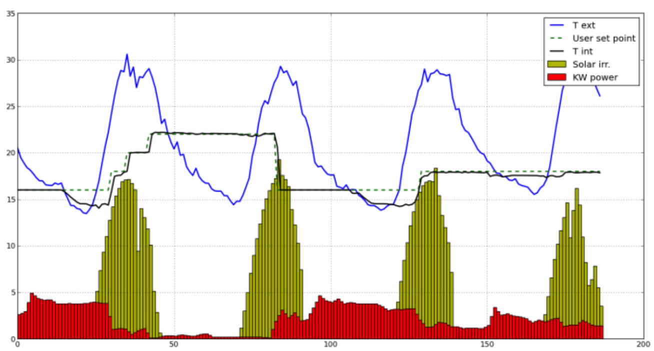

Fig. 4: The overall data set measured in the thermal lab located at Roio's Monteluco hill. "T_{int}" is the output coming from the global system model fitted with components obtained by symbolic regression machine learning. The lower signals, Solar irradiance and kW are out of scale, just for showing their shape over time. All signals are sampled every 30 minutes

Target variables that constitute the forecaster model are energy consumption in function of all the remaining system variables and indoor temperature in function of the remaining system variables, i.e. temperatures sensors across the room. Results after running Eureqa on real data are depicted in Fig. 4. Fig. 5 depicts the data fitting of the Eureqa's model data.

The models that we obtained were used both for running simulation of different controlling agents and for predicting variables values in near future as needed by some agents controlling strategies. We run two simulations with four different agents. The first set of four simulates the behavior of simple heuristic strategies. The second set simulate the same agents when their strategies are improved with some predictive ability.

[8] heating, ventilation and air conditioning

A. Non-predictive control

With the aim of validating the synthetic models, and of showing that better energy managements than usual thermostatic control are possible, we used the model for simulating the behavior of the system when controlled by four simple controlling agents using different strategies with which they would act in setting the set point of the air conditioner. The agents behaviors we analyzed are:

A) The picky agent: It acts by keeping the thermostatic set point of the air conditioner as set by the user's dynamical choice. This agent is picky and strict -and in fact implemented as null- as it relies only on the air conditioner hardware and the user's setting

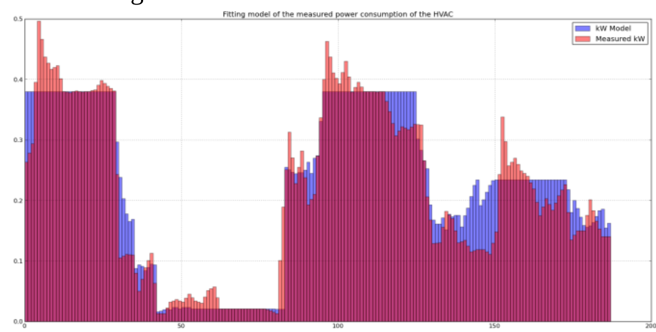

Fig.5: Electrical power consumption model fitted from thermal lab measurements with components obtained by Eureqa symbolic regression program [18,19], in function of external weather conditions and user set point.

B) The cheap agent: It acts by keeping the set point at the extreme of the comfort interval, in this case defined as the set point chosen by the user + 3° Celsius. This agent is cheap as it tries to save energy by keeping temperature at the highest possible point within the defined comfort interval as chosen by the user.

C) The parsimonious agent: It acts by increasing the set point to the highest possible within the comfort interval, behaving as the cheap agent, if both outside temperature and solar radiation are increasing, or decreasing, among the out of thermal equilibrium condition principle. It is parsimonious as it accepts to relax the strict adherence to the set point chosen by the user when it expects a heat wave that would be expensive to combat or when is coming a natural cooling period. On the other hands, when trends have different sign, the set point correction is zero.

D) The heuristic agent: It acts according to a rule that has been heuristically constructed after an human guided analysis of the behavior of the system trends, observing real data and simulated scenarios. It's a variation over the parsimonious agent behavior that can be summarized as follows: given the trends of both external temperature and solar irradiance by means of filtered discrete derivatives, their respective amplitudes are summed and the sign of the result Rt is considered. If Rt is positive the comfort is relaxed. Rt can be positive either if both temperature and solar are increasing, either if one of them has a prevalent increasing trend.

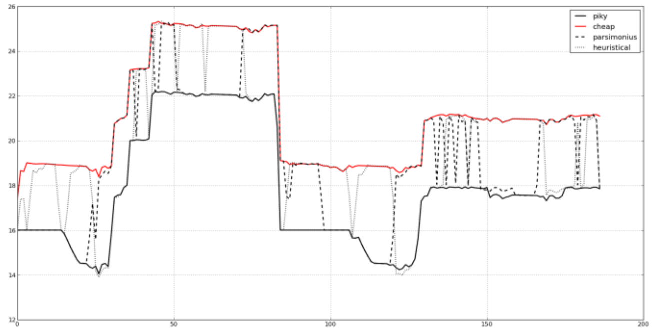

Fig. 6: Indoor temperature obtained in scenarios of non-predictive agents. Simulation done over two days of real weather condition during September 2013. Steps are due to the dynamical user set point, not shown for clarity, that drives the indoor temperatures evolution.

TABLE VII NON-PREDICTIVE AGENTS ENERGY AND COMFORT PEFORMANCE.

Agent	*kWh*	*Discomfort time %*	*Total discomfort*
picky	40.99	1.60 %	23.38
cheap	12.58	34.76 %	549.77
parsimonious	28.15	8.02 %	256.82
heuristic	21.89	13.90 %	351.46

In Fig. 6 we show the results of the four simulations and in Table 1 we report the total energy consumption and the estimated discomfort in the simulated time period. Discomfort is measured both as number of samples outside the comfort interval and as integral of inside temperature distance from the set point chosen by the user. As we see, the heuristic agents C and D achieve an energy consumption in between the range from the maximum consumption of the strict agent A and the minimum of the cheap agent B, with a comfort in the range of the maximum achieved by A and the minimum achieved by B.

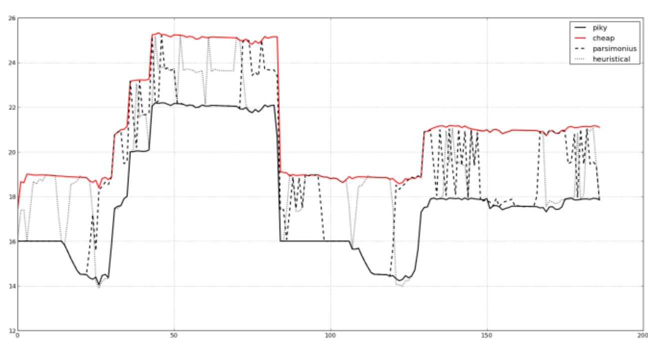

Fig.7 Indoor temperature obtained in the predictive agents scenarios. Simulation done over two days of real weather condition during September 2013.

B. Predictive control

The second experimentation was obtained by providing all agents with a rule that would decrease the set point of the air conditioner if they would predict an indoor temperature beyond the comfort interval. For implementing this rule the agents use the constructed model in two ways. First they use it to predict energy consumption in the following time period given other variables, and in particular actual controlled set point. External environment variables are predicted with different models: temperature Text is derived from the daily temperature distribution function from ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) manual [22], in function of the moving estimate of maximum and minimum temperature of the day. Solar irradiance S has been with Eureqa symbolic regression program fitting it against time of the year, with samples taken over the previous 2 weeks, so the get the best approximation of future solar irradiance taking into account the local shading near the thermal laboratory at Roio's hill.

Text and S are again used to predict indoor temperature in the following time period together with the predicted energy consumption, measured in kWatts over the sampling period.

TABLE IVIII PREDICTIVE AGENTS ENERGY AND COMFORT PEFORMANCE. IN THE RIGHTMOST COLUMN SHOWS THE PERCENTUAL IMPROVEMENT IN COMFORT OF THE FORECASTING AGENTS..

Agent	*kWh*	*Discomfort time %*	*Total discomfort*	*Improvement*
picky	40.99	1.60 %	23.38	0 %
cheap	12.58	34.76 %	549.77	0 %
parsimonious	30.30	2.14 %	206.12	19.74 %
heuristic	23.98	1.60 %	300.42	14.52 %

In Fig.7 we show the results of the simulations and in Table 2 we report the total energy consumption and the estimated discomfort in the simulated time period. Also, so as to get an objective prove of the more efficient functioning of the predictive agents we computed the total comfort improvement over their non-predictive version. As we see, predictive ability does not improve performance of the picky and the cheap agent but it does improve performance of the parsimonious and the heuristic agent. In fact they both achieve about the same discomfort time as the picky agent with a sensible energy saving. Moreover both the predictive versions of the parsimonious and heuristic agent improve total comfort over their non-predictive versions, with a relative smaller increase in energy consumption.

V. EXPERIMENTAL SETUP

The thermal laboratory is located at Roio's Monteluco hill, coordinates 42.33 N 13.37 E, 1100 from sea level. The room is 8x8x3 mt, with a small window (1msq) on the east wall and a wooden door on the south wall. The HVAC system is made by a Mitzubishi MSZ-FD25VA inverter thermal pump and an external chiller MUZ-FD25VA. Temperatures are measured by means of 3 dry bulb PT100 thermo-resistors sensors, at different distance from the air conditioner, connected to a Delta-T logger DL2e.

The thermal control is supervised with a domotic network. The HVAC consumption is measured with toroidal sensors over power lines. The set point is set to the HVAC by means of a IR-remote emulator. The sampling frequency is set at 30 minutes, during which temperatures are averaged and instantaneous HVAC power level is accumulated. There is also an external weather station Geoves Micro 3 that measures solar irradiance, ambient temperatures, wind direction/amplitude and humidity.

VI. Related Work

A. Active Logic Programming

In the field of Active Logic Programming, we have chosen to use DALI [4, 6] for its unique features in respect of the other development frameworks that are available. The DALI semantics is fully defined in [4], while the operational semantics of the interpreter is described in [8]. A DALI agent is a logic program that contains a particular kind of rules, reactive rules, aimed at interacting with an external environment. The environment is perceived in the form of external events, that can be exogenous events, observations, or messages by other agents. In response, the agent can perform actions, send messages, adopt goals, etc. The reactive and proactive behavior of the agent is triggered by several kinds of events: external events, internal, present and past events. When an event arrives to the agent from its “external world”, the agent can perceive it and decide to react. However, when an agent perceives an event from the “external world”, it doesn’t necessarily react to it immediately: it has the possibility of reasoning about the event, before (or instead of) triggering a reaction. Furthermore, internal events make a DALI agent proactive.

In particular, [5] proposes an extension so to manage complex reaction in rule-based logical agents using a DALI-like syntax which associates a set of preference rules, that can express the performance goals directly into the language.

The literature in MAS is wide and large; see [14] for a survey. However, there are some points in contact with different solutions, both at the domain and at a design and development levels.

3APL [9, 10] is a programming language and a platform specifically tailored to implement MAS, where the agents are designed in terms of “data structure” or “mental attitudes” (beliefs, goals, plans and reasoning rules) and “deliberation process” – implemented as programming instructions. Based on its beliefs, an agent can reach its goals by planning its actions thanks to the deliberation cycle, that can lead also to the check and revision of its mental attitudes. Although 3APL is based on the concepts of rules and planning, it lacks to implement the idea of event, unlike for instance DALI. 3APL has been used mostly to realize application for virtual training (e.g. [17]).

A similar approach is known as KGP (Knowledge, Goals and Plans), which is based on logic programming with priorities, taking beliefs, desires and intentions as a starting point, but adding reasoning capabilities, state transitions and control – see [15]. Furthermore, it is implemented directly in computational logic. KGP could be a valid alternative candidate compared to DALI.

METATEM (and its extension Current MERATEM) [1] is a language based on first-order linear temporal logic, and thus it is suitable for temporal planning and temporal knowledge representation. At the basis it has concepts such as beliefs, intentions, goals and plans, but the very fundamental rules are of the form “past and present formula implies present and future formula“ [16]. So, like DALI, at the center of METATEM there are the concept of time and the idea that the past determines the present and the future, but it has no different classes of events and METATEM agents are just reactive agents, unlike DALI. METATEM can have a wide range of applications (e.g. patient monitoring, fault tolerance system, process control etc.) [13, 12], but as far as the authors know, it has not been used for the energy management of a building.

B. Energy Saving and Air Conditioning

From a classical control point of view, the work in [20] developed cost efficient control strategies to achieve optimal energy and acceptable comfort conditions. The importance of agents based intelligent control systems for indoor building environments, coordinated through MAS, in the context of an energy efficient building has been reviewed in [21], were an evolutionary algorithm shapes the fuzzy knowledge base of a multilevel hierarchical MAS, to take the overall user comfort, including thermal, visual and air ventilation, under control.

VII. Conclusion

The experimental simulations demonstrate feasibility and the effectiveness of predictive agent based control towards providing a range of different behaviors to adhere to a given goal. This preliminary results calls for embedding predictive capabilities in planners as outlined

Acknoiwledgment

Giovanni De Gasperis and Pasquale Caianiello dealt with the domain problem, the case study, the prosumer forecaster, and the symbolic regression machine learning, while Mario Gimenez De Lorenzo cured the experimental setup, real data collection and model simulations. Stefania Costantini leads the research group devoted to logical agents and contributed defining the DALI rule set to handle user preferences. The final logical agent-based approach is the result of the work of the whole team. We also wish to thank Prof. Francesco Muzi and Prof. Fulvio Marcotullio from the Department of Industrial and Information Engineering and Economics at the University of L’Aquila, for the insightful discussions that seeded this work.

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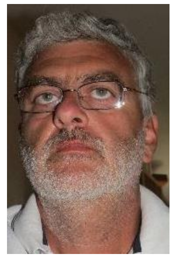

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A Constraint-Based Model for Fast Post-Disaster Emergency Vehicle Routing

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Abstract **— Disasters like terrorist attacks, earthquakes, hurricanes, and volcano eruptions are usually unpredictable events that affect a high number of people. We propose an approach that could be used as a decision support tool for a post-disaster response that allows the assignment of victims to hospitals and organizes their transportation via emergency vehicles. By exploiting the synergy between Mixed Integer Programming and Constraint Programming techniques, we are able to compute the routing of the vehicles so as to rescue much more victims than both heuristic based and complete approaches in a very reasonable time.**

Keywords **— Disaster Recovery, Decision Support Systems, Constraint Programming, Mixed Integer Programming.**

I. Introduction

Disasters are unpredictable events that demand dynamic, real-time, effective and cost efficient solutions in order to protect populations and infrastructures, mitigate the human and property loss, prevent or anticipate hazards and rapidly recover after a catastrophe. Terrorist attacks, earthquakes, hurricanes, volcano eruptions *etc.* usually affects a high number of persons and involve a large part of the infrastructures thus causing problems for the rescue operations which are often computationally intractable. Indeed, these problems have been tackled by using a *pletora* of different approaches and techniques, ranging from operational research to artificial intelligence and system management (for a survey please see [1]).

Emergency response efforts [2] consist of two stages: pre-event responses that include predicting and analyzing potential dangers and developing necessary action plans for mitigation; post-event response that starts while the disaster is still in progress. At this stage the challenge is locating, allocating, coordinating, and managing available resources.

In this paper we are concerned with post-event response. We propose an algorithm and a software tool that can be used as a decision support system for assigning the victims of a disaster to hospitals and for scheduling emergency vehicles for their transportation. Even though our algorithm could be used to handle daily ambulance responses and routine emergency calls, we target specifically a disaster scenario where the number of victims and the scarcity of the means of transportation are usually overwhelming. Indeed, while for normal daily operations the ambulances can be sent following the order of the arrival of emergency calls, when a disaster happens this First In First Out policy is not more acceptable. In these cases, the number of victims involved and the quantity of damages require a plan and a schedule of rescue operations, where usually priority is given to more critical cases, trying in any case to maximize the number of saved persons. In this context there are clearly also essential ethical issues which we do not address in this paper (for example, is ethically acceptable not to save a person immediately if this behavior allow us to save more persons later on?).

Our tool then assumes a simplified scenario where the number, the position and the criticality of victims is known.

The tool computes solutions that try to maximize the global number of saved victims. In many practical cases finding the optimal solution in not computationally feasible, hence we use a relaxation of the pure optimization problem. Our approach uses a *divide-et-impera* technique that exploits both Mixed Integer Programming (MIP) and Constraint Programming in order to solve the underlining assignment and scheduling problems.

To evaluate the effectiveness of our approach we have compared it against two alternative approaches: on one hand, a greedy algorithm based on the heuristic that send the ambulances first to the most critical victims and later to the others and, on the other hand, a complete algorithm that tries to find the optimal solution in terms of number of rescued victims.

Empirical results based on random generated disaster scenarios show that our approach is promising: it is able to compute the schedule usually in less than half a minute and almost always save more victims than other approaches.

Paper Structure. In Section II we define the model we are considering while in Sections III and IV we present the algorithms and the tests we have conducted. In Section V we present some related work. We conclude giving some

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directions for future work in Section VI.

II. Model

In the literature a lot of models have been proposed to abstract from a concrete disaster scenario. Some of them are extremely complex and involve a lot of variables or probability distributions [3], [4]. For the purposes of this paper we adapt one of the simplest models, following [5], which considers only three entities: victims, hospitals, and ambulances. However, note that the flexibility of the Constraint Programming paradigm would also allow to handle more sophisticated models. Formally, we consider three disjoint sets:

- the set of the ambulances $Amb := \{A_1, \ldots, A_m\}$;
- the set of the victims $Vict := \{V_1, \ldots, V_n\}$;
- the set of the hospitals $Hosp := \{H_1, \ldots, H_p\}$;

and we assume to know the following data:

- the spatial coordinates $sa_i \in \mathbb{R}^2$ of every ambulance A_i;
- the spatial coordinates $sv_j \in \mathbb{R}^2$ of every victim V_j;
- the spatial coordinates $sh_k \in \mathbb{R}^2$ of every hospital H_k;
- the capacity $ca_i \in \mathbb{N}$ of every ambulance A_i;
- the capacity $ch_k \in \mathbb{N}$ of every hospital H_k;
- the estimated time to death $ttd_j \in \mathbb{N}$ of every victim V_j;
- the estimated dig-up time $dig_j \in \mathbb{N}$ of every victim V_j, *i.e.* the time needed by the rescue team to be able to rescue the victim as soon as the ambulance arrives on the spot;
- the a function $T : \mathbb{R}^2 \times \mathbb{R}^2 \to \mathbb{N}$ that estimates the time needed by an ambulance to move between two given points;
- the initial time $start_i \in \mathbb{N}$ an ambulance become available (an ambulance may be dismissed or already busy when the disaster strikes).

We are well aware that, especially in a disaster scenario, these data may be difficult to retrieve, imprecise and unreliable. Nevertheless our model can exploit these data to compute a first solution and then later, when the information become more precise, it can be rerun to improve the computed solution. Moreover, in order to get these information one can use the results of such works like [6], [7] that allow to esteem the time to death of a civilian or to find the best routes to reach the victims.

Assuming that all the above information are known, our goal is then to find as quickly as possible an optimal scheduling of the ambulances in order to bring the maximal number of alive victims to the hospital. Of course, solving optimally such a scheduling may be computationally unfeasible, especially in the case of a large number of victims. Moreover, in our scenario, a fast response of the scheduling algorithm is important for different reasons. First of all, the quicker the response is, the faster we can move the ambulances and therefore more victims may be saved. In addition, waiting for a long time may be useless because usually information rapidly changes (*i.e.* more victims come, the criticality of the patients vary, the hospitals may have damages or emergencies, ambulances can be broken). Hence, spending a lot of time for computing an optimal solution that in few seconds could become non optimal may result in a waste of resources and then lead to the impossibility of saving some victims. On the other hand, a purely greedy approach that at each stage makes the locally optimal choice (according to heuristics such as the seriousness or the location of the victims) would be definitely faster, but could result in a smaller global number of victims saved.

III. Procedure

As previously mentioned, our aim is to find the best possible compromise between the optimality of the ambulances scheduling and the time it takes to find it.

For this reason, we propose an approach that at the same time allows to compute a solution within a reasonable time limit and still allows us to save more victims than greedy strategies. Motivated by the success of hybrid algorithms on problems of resource assignment and scheduling [8], we developed a mixed approach that basically lies in the interaction of two phases: the *allocation phase*, in which we try to allocate as many victims as possible to ambulances and hospitals, and the *scheduling phase*, in which we compute the path that each ambulance must follow in order to bring the victims to the hospitals. In this section we first detail these two phases and then we show the pseudo-code explaining the interplay needed between the allocation and scheduling phase to solve the problem.

A. Allocation

In the allocation phase, we relaxed some constraints of the problem assuming that every ambulance can save in parallel all the victims it contains (in other terms, each ambulance with capacity *c* can be seen as the union of *c* distinct ambulances with capacity 1). The allocation of every victim to an ambulance and a hospital is performed by solving a Mixed Integer Programming problem by using two kind of binary variables, denoted by $a_{i,j}$ and $h_{j,k}$. The variable $a_{i,j}$ is set to 1 if and only if the victim V_j is assigned to the ambulance A_i, while $h_{j,k}$ = 1 if and only if the victim V_j is assigned to the hospital H_k. The constraints that we enforced are the followings:

- $\sum_{i=1}^{m} a_{i,j} \leq 1$ (for each $j = 1, \ldots, n$ a victim V_j can not be assigned to more than one ambulance);
- $\sum_{k=1}^{p} h_{j,k} \leq 1$ (for each $j = 1, \ldots, n$ a victim V_j can not be assigned to more than one hospital);

- $\sum_{j=1}^{n} a_{i,j} \leq ca_i$ (for each i = 1, ..., m the maximum number of patients on an ambulance A_i must not exceed its capacity);
- $\sum_{j=1}^{n} h_{j,k} \leq ch_k$ (for each k = 1, ..., p the maximum number of victims in a hospital H_k must not exceed its capacity);
- $\sum_{i=1}^{m} a_{i,j} = \sum_{k=1}^{p} h_{j,k}$ (for each j = 1, ..., n a victim V_j is assigned to an ambulance A_i if and only if V_j is assigned to an hospital H_k: there must not be *'dangling'* victims);
- $\sum_{i=1}^{m} \sum_{k=1}^{p} (start_i + T(sa_i, sv_j)) \cdot a_{i,j} + dig_j + T(sv_j, sh_k) \cdot h_{j,k} < ttd_j$ (for each j = 1, ..., n the time an ambulance A_i needs to reach a victim V_j, dig up and bring her to an hospital H_k is enough to save her).

Since the objective of the MIP problem is to try to maximize the number of rescued victims, we defined an objective function which takes into account both the seriousness and the location of the victims. Specifically, we require the maximization of the following objective function:

$$\sum_{i=1}^{m} \sum_{j=1}^{n} \frac{1}{\alpha_{i,j}} \cdot a_{i,j} + \sum_{j=1}^{n} \sum_{k=1}^{p} \frac{1}{\eta_{j,k}} \cdot h_{j,k}$$

where:

$$\alpha_{i,j} := (ttd_j - dig_j) \cdot (start_i + T(sa_i, sv_j))$$
$$\eta_{j,k} := (ttd_j - dig_j) \cdot T(sv_j, sh_k).$$

Recall that solving this problem does not necessarily mean to solve the overall problem: the solution found gives an esteem of the victims that could be saved and a preliminary allocation of every victim to an ambulance and a hospital. Indeed, since this is a relaxation of the original problem, it may be possible that not all the victims allocated to an ambulance may be saved. Anyway, it is worth noticing that the allocation guarantees that at least one victim for ambulance can be rescued. Also, there are no restrictions on the number of hospitals that an ambulance can visit.

B. Scheduling

Once the victims have been allocated by the first phase, the scheduling phase allows to define the path that each ambulance must follow in order to maximize the number of victims saved. After solving the above MIP we can assume that the allocation phase identifies a partition $\Pi := \{A_1^*, \ldots, A_m^*\}$ where for each i = 1, ..., m we define:

$$A_i^* := \{(V_j, H_k) : V_j \text{ is transported to } H_k \text{ by } A_i\}.$$

The ambulance scheduling for each ambulance A_i is then obtained by computing a *minimal Hamiltonian path* in a weighted and direct graph derived from A_i^*. Given such an A_i^*, let us consider the graph $\mathcal{G}_i := (\mathcal{N}_i, \mathcal{A}_i, \omega_i)$ where:

- the set of nodes $\mathcal{N}_i$ corresponds to a set of spatial coordinates, in particular each node represents either:
  - the initial position sa_i of the ambulance A_i;
  - the position of the victims sv_1, ..., sv_{n_i} that A_i transports;
  - the position of the hospitals sh_1, ..., sh_{p_i} that A_i visits;
- the set of arcs $\mathcal{A}_i \subseteq \mathcal{N}_i \times \mathcal{N}_i$ corresponds to the movements that A_i can do from one node to another and it is defined as follows:
  - $(sa_i, sv_j) \in \mathcal{A}_i$ (A_i can go to any assigned victim V_j from its initial position);
  - if V_j is assigned to H_k, then $(sv_j, sh_k) \in \mathcal{A}_i$ (A_i can bring a victim to its assigned hospital);
  - if $V_j \neq V_{j'}$ are assigned to the same hospital, then $(sv_j, sv_{j'}) \in \mathcal{A}_i$ (A_i can move from an assigned victim to another one, but no victims assigned to different hospitals can be simultaneously on A_i);
  - if V_j is not assigned to H_k, then $(sh_k, sv_j) \in \mathcal{A}_i$ (A_i can move from an hospital to a victim only if she is not assigned to such hospital);
  - no other arcs belongs to $\mathcal{A}_i$ (no other move is allowed).
- the weight function $\omega_i : \mathcal{N}_i \times \mathcal{N}_i \to \mathbb{R}$ corresponds to the estimated time for moving from one point to another, including dig-up time:
  - $\omega_i(sa_i, sv_j) := start_i + T(sa_i, sv_j) + dig_j$
  - $\omega_i(sv_j, sh_k) := T(sv_j, sv_k)$
  - $\omega_i(sv_j, sv_{j'}) := T(sv_j, sv_{j'}) + dig_{j'}$
  - $\omega_i(sh_k, sv_j) := T(sh_k, sv_j) + dig_j$

Therefore, if A_i has assigned n_i victims and has to visit p_i hospitals, the number of nodes will be $|\mathcal{N}_i| = 1 + n_i + p_i$ while the number of arcs will be $|\mathcal{A}_i| = n_i^2 + n_i \cdot p_i$.

The scheduling of each ambulance A_i can be computed by finding the minimum cost Hamiltonian path $P_1 \to P_2 \to \cdots \to P_{n_i}$ in $\mathcal{G}_i$ where:

- P_1 corresponds to the initial location sa_i of A_i;
- P_j for each $1 < j < n_i$, corresponds either to the location of a victim or the location of an hospital;
- P_{n_i} is the location of an hospital of A_i^*;
- $\Omega < ttd_i$, where Ω is the total cost of the path and ttd_i the time-to-death of each victim of A_i^*.

The scheduling phase can therefore be mapped into a *Constraint Optimization Problem* (COP) with the goal of minimizing Ω and solved by using constraint programming techniques.

As already stated, it may be the case that not all the victims allocated to an ambulance may be saved, since differently to what happen in the relaxed problem now an ambulance has to save the victims sequentially. When this happens we have to compute a schedule that saves a maximal subset of such victims. However, instead of considering as maximal subset the one which contains the greater number of elements, we choose the one which has the maximum *priority value* that is calculated as follows. We first compute the remaining time $RT_i := ttd_i - dig_i$ of each victim by subtracting her dig-up time from the expected time to death. Then, given a subset of victims $W \subseteq Vict$, we set its priority to $w = \sum_{V_j \in W} \frac{1}{RT_j}$ (bigger values of w means higher priority). We decided to use this sum to evaluate the priority because, analogously to what happens for the harmonic average, the sum of the reciprocal gives priority to the victim having least remaining time and it mitigates at the same time the influence of large outliers (i.e. victims with big remaining time that can be easily saved later).

When an ambulance is scheduled, the model is updated accordingly and the allocation phase is possibly restarted in order to try to allocate the victims which have not yet been assigned. The procedure ends when no more victims can be saved.

C. A&S Algorithm

Listing 1: A&S Algorithm

```
1  ALLOCATE_AND_SCHEDULE(Amb, Vict, Hosp):
2    while Vict ≠ ∅:
3      REMOVE_NOT_RESCUABLE_VICTIMS(Vict)
4      Π = ALLOCATE(Amb, Vict, Hosp)
5      sorted_ambs = SORT_AMBS_BY_PRIORITY(Π)
6      foreach A_i ∈ sorted_ambs:
7        V = VICTIMS(A_i, Π)
8        if V ≠ ∅:
9          (Σ, Ω) = SCHEDULE(A_i, V, Π)
10         if Σ is not feasible:
11           w = 0
12           Ω = +∞
13           foreach k ∈ [|V| − 1, ..., 1]:
14             foreach h ∈ [1, ..., (|V| choose k)]:
15               V′ = GET_SUBSET(h, k, V)
16               w′ = Σ_{v_l ∈ V′} 1/ttd_l
17               if w′ ≥ w:
18                 (Σ′, Ω′) = SCHEDULE(A_i, V′, Π)
19                 if Σ′ is feasible ∧
20                   (w' == w → Ω′ < Ω):
21                   w = w′
22                   Ω = Ω′
23                   Σ = Σ′
24         start_i = Ω
25         foreach H_k ∈ Hosp:
26           ch_k = ch_k − NO_OF_VICTIMS(Σ, H_k)
27         sa_i = LAST(Σ)
28         Vict = Vict \ VICTIMS(Σ)
29         schedule[A_i].append(Σ)
30         if VICTIMS(Σ) ≠ V:
31           break
32   return schedule
```

The main procedure called Allocate & Schedule (A&S) and presented in Listing 1 takes as input the set of ambulances Amb, the set of victims $Vict$, and the set of hospitals $Hosp$. It consists of a cycle where, first of all, the victims that can not be saved (*i.e.* victims with a remaining time less than or equal to 0) are removed. This operation is performed by the external function REMOVE_NOT_RESCUABLE_VICTIMS at line 3.

The ALLOCATE function solves the MIP problem described in Section III-A and returns the allocation of every victim to one ambulance and one hospital. The ambulances are then sorted by the function SORT_AMBS_BY_PRIORITY according to the sum of the priority values of the victims assigned to each ambulance; in this way, the schedule of the ambulances which transport victims with higher priority is performed earlier.

The nested loop starting at line 6 is responsible to compute the schedule of all the ambulances. Considering the ambulance A_i, in line 7 the variable V is defined to be the set of the victims assigned to A_i. If V is not empty then SCHEDULE(A_i,V,Π) returns a possible schedule $\sum$ and its cost Ω for the ambulance A_i. This is done following the procedure described in Section III-B. If the schedule problem has no solution (line 10) then another solution that involves less victims is computed (lines 11-23). In particular, the priority of the set of the victims w is initialized to 0, while the cost of the solution Ω to +∞ (lines 12-13).

The loops enclosed between lines 13 and 23 have the aim of calculating a maximum eligible subset of victims, *i.e.* a subset V' of V that both maximizes the value of $\sum_{v_l \in V'} \frac{1}{ttd_l}$ and admits a feasible schedule. In order to compute all the subsets of V we exploit the function GET_SUBSET(*i, k, A*) that returns the *i*-th subset (*w.r.t.* lexicographic order) among all the $\binom{|A|}{k}$ subsets of A with cardinality k. Note that computing all the subsets is in general exponential on the capacity of the ambulances. However, in real cases, this can be computationally feasible since the capacity of the ambulances is usually small. In line 15 a subset V' is retrieved and its weight is computed in line 16. In case the weight is greater than the weight of the current solution, a schedule of the ambulance A_i for victims in V' is computed (line 18). If the schedule is feasible and has a lower cost in case of equal weight then the current schedule $\sum$, the current weight w and the current cost Ω are updated.

By construction, once exiting from the above loops a schedule that involves at least a victim is always found. Then, we just need to update the model. First, we update the start time of the ambulance A_i with the total cost of the schedule $\sum$ (line 24). Then, for each hospital H_k we decrease the hospital capacity ch_k according to the number of victims that A_i brings to them (lines 25-26). The new spatial location of A_i is set to the value of the last hospital it visits (line 27) and we remove from $Vict$ all the victims that A_i has rescued. Finally, the schedule $\sum$ is added to the associative array *schedule* that is the output of the A&S procedure.

In case only a part of the victims allocated to the ambulance A_i were saved (line 30) the cycle starting at line 6 is interrupted in order to compute a new allocation that may allocate the remaining victims to other ambulances.

The algorithm terminates when no more victims can be saved. From the computational point of view this algorithm cyclically solves MIP and COP problems, which are well known NP-hard problems. However, by exploiting the relaxation of the MIP problem, on one hand, and the limited size of the COP problems, on the other, it is possible to get quickly optimal solutions by exploiting current MIP and COP solvers. An empirical proof of this is provided in the next section.

IV. Tests

We did not find in the literature suitable and extensive benchmarks of disaster scenarios that we could use to evaluate and compare the performances of our approach. For this reason, in order to evaluate our algorithm we extended the methodology used in [9]. In particular, we built random generated scenarios obtained by varying the number of hospitals in the set {1, 2, 4}, the number of ambulances in {4, 8, 16, 32, 64}, and the number of victims in {8, 16, 32, 64, 128, 256, 512}. The position of each entity was randomly chosen in a grid of 100×100 by using the Euclidean distance to estimate the time needed for moving from one point to another.

The capacities of the ambulances and the hospitals were selected randomly in the intervals [1..4] and [300..1000], respectively, while the dig-up time and the time to death of every victim were randomly chosen in [5..30] and [100..1000], respectively. For i = 1, ..., m we considered initially $start_i = 0$.

Listing 2: GREEDY Algorithm

```
1  GREEDY(Amb, Vict, Hosp):
2    REMOVE_NOT_RESCUABLE_VICTIMS(Vict)
3    sorted_victs = SORT_VICTS_BY_PRIORITY(Vict)
4    while sorted_victs ≠ []:
5      V_j = sorted_victs.pop()
6      A_i = CLOSEST_AMB(V_j)
7      schedule[A_i].append((start_i, sv_j))
8      H_k = CLOSEST_HOSP(V_j)
9      deadline = ttd_j
10     position = sv_j
11     victims = 1
12     time = start_i + T(sa_i, sv_j) + dig_j + T(sv_j, sh_k)
13     hosp_time = T(sv_j, sh_k)
14     foreach V_l ∈ sorted_victs
15       t = T(position, sv_l) + dig_l + T(sv_l, sh_k) − hosp_time
16       if victims < ca_i ∧ victims < ch_k ∧
17         time + t < deadline ∧ time + t < ttd_l:
18           hosp_time = T(sv_l, sh_k)
19           sorted_victs.remove(V_l)
20           schedule[A_i].append((position, sv_l))
21           deadline = min(deadline, ttd_l)
22           victims = victims + 1
23           time = time + t
24           position = sv_l
25     schedule[A_i].append((position, sh_k))
26     start_i = time
27     sa_i = sh_k
28     ch_k = ch_k − victims
29     REMOVE_NOT_RESCUABLE_VICTIMS(sorted_victs)
30   return schedule
```

To increase the accuracy and the significance of the results we tested our approach by running the experiments 20 times for each different scenario and by measuring the average number of rescued victims as well as the time required to solve the problem. In total we tested then 105 different scenarios.

For every different scenario we compared the results of A&S *w.r.t.* a greedy approach GREEDY and a complete approach COMP that are used as baselines. In the following, before reporting the results, we briefly explain the algorithms we used as baselines.

A. GREEDY

GREEDY is a heuristic based algorithm that at each time tries to assign the most critical victims to the closest available ambulance and then such ambulance to the closest available hospital. Moreover, GREEDY also looks if in the path from the ambulance to the hospital it is possible to save other critical victims.

The pseudo-code of GREEDY is summarized in Listing 2. As in Listing 1, the main procedure takes as input the ambulances, the victims, and the hospitals. After removing all the non rescuable victims (line 2), it sorts all the victims by decreasing priority (line 3). At line 4 it starts the main loop, which is repeated until no more victims can be saved. First, the most critical victim is extracted into the variable V_j (line 5): this is the victim that the ambulance will save first. In line 6 the function CLOSEST_AMB is used to retrieve the closest free ambulance A_i to victim V_j while CLOSEST_HOSP is a function that returns the closest available hospital to V_j. In lines 9-13 we define some auxiliary variables for computing the schedule of the ambulance. In particular `deadline`, `position`, and `victims` are used to store respectively the minimum time to death of the transported victims, the position of the last victim of the schedule, and the total number of victims on the ambulance. The variable `hosp` keeps track of the total cost of the path from the ambulance to the hospital while `hosp_time` represents instead the cost of the last segment of the path, i.e. time needed for moving from the last victim to the hospital H_k.

The ambulance A_i is immediately sent to hospital H_k unless there are other victims that can be saved along the way. In order to look for such additional victims, we use a loop that scans each remaining victim V_l of `sorted_victs` (line 14). Within the cycle, in line 15 we evaluate the cost `t` needed for carrying the victim V_l to H_k. If such a transportation is possible, that is the capacity of A_i and H_k is not exceeded and there is enough time for saving all the victims of A_i (lines 16-17) then in lines 18-25 we update the ambulance schedule by updating the corresponding variables.

When the foreach cycle terminates, all the victims that could be saved by A_i (according to the heuristic) have been considered and therefore the ambulance is sent to the hospital. Therefore, in lines 26-28 we update the start-time of A_i, its location and the capacity of the hospital. Finally, in line 29 we remove all the not rescuable victims and the while cycle starts again until no more victims can be saved.

B. COMP algorithm

COMP is an algorithm that maps the rescue problem into a COP and computes the schedule of every ambulance without a pre-allocation phase. COMP is a complete algorithm: it tries to maximize the number of rescuable victims and when it terminates with success it always returns an optimal solution.

COMP assigns to all the ambulances, victims, and hospitals an unique identifier. In particular all the ambulances of Amb have an identifier $i \in D_a := [0..m]$, all the victims of $Vict$ have an identifier $j \in D_v := [m+1..m+n]$ and all the hospitals in $Hosp$ have an identifier $k \in D_h := [m+n+1..m+n+p]$.

The schedule of ambulance A_i at its j-th *round* (where by round we mean a path from its starting point to exactly one hospital) was encoded with an array $R_{i,j}$ of integer variables indexed from 0 to $ca_i + 2$. We then defined $m \cdot n$ arrays containing the identifiers of the victims and the hospital that each ambulance should visit in sequence.

$R_{i,j}[0] \in \{i\} \cup D_h$ is the index corresponding to the location of the ambulance A_i at the beginning of the j-th round. Since in the first round the starting point of A_i is always $start_i$ and in the following rounds the starting point is always the location of a hospital, we have $R_{i,1}[0] = i$ and $R_{i,j}[0] \in D_h$ for $i = 1,..., m$ and $j = 2,..., n$.

$R_{i,j}[1],\ldots,R_{i,j}[ca_i] \in \{0\} \cup D_v$ are instead the indexes of the victims that A_i can rescue. In case the ambulance round was not filled completely one or more elements of $R_{i,j}$ are set to 0, signaling for every element set to 0 that a place was not used.

The last two elements of the arrays contain the index of the hospital where the ambulance ends its round and the total cost of the round. Note that each $R_{i,j}$ definition also entails that a victim can not be assigned to more than one hospital and that the maximum number of victims on A_i must not exceed its capacity ca_i. Additional constraints are needed in order to achieve the soundness of the solution and to reduce the search space. In particular, we added constraints enforcing that:

- the total cost of each round $R_{i,j}$ has to be lower than the time to death of each victim of $R_{i,j}$;
- if $R_{i,j}$ does not save any victim then all the subsequent rounds will not save any victim;
- the maximum number of victims in a hospital H_k must not exceed its capacity ch_k;
- a victim can occur in at most one round.

The objective of the COP is maximize the number of rescued victims, *i.e.* maximize the cardinality of the disjoint union of the victims assigned to each round. In order to encode the problem, we used basic constraints (such as <, +, ...) as well as *global constraints* [10] (namely, *element*, *alldifferent_except_0*, and *count*).

As can be imagined, solving such a problem may consume too many resources. In order to conduct the experiments using scenarios of nontrivial size we imposed some limitations that in some cases may result in a loss of completeness. We first limited the number of rounds for each ambulance to the ratio between victims and ambulances whenever the number of victims was greater than the number of ambulances. Then, during the computation of the solutions, we have limited the use of the virtual memory to 50% of the total available space and set a timeout of 300 seconds keeping the best solution founded up to that time if no solution was proven optimal.

C. Results

Fig. 1 shows the average percentage of rescued victims obtained by using A&S, GREEDY, and COMP approaches. The x-axis values represent scenarios sorted lexicographically by increasing number of victims, ambulances, and hospitals (labels are omitted for the sake of readability, since each x-value is actually a triple of values).

Our approach is in average able to rescue the 87.08% of the victims (from a minimum of 18.02% to a maximum of 100%). Considering the median value, in half of the scenarios we are able to rescue more than 99.38% of the victims.

In only 2 cases (0.02% of the scenarios) GREEDY is better than our approach, while in only one case COMP is better than A&S. However, in these few cases the difference of saved victims is minimal (between 0.31% and 1.48%) while the gap between A&S and GREEDY or COMP can reach peaks of about 78% and 100% respectively. In average, A&S is able to rescue about 31.03% of victims more than GREEDY and 59.38% more than COMP.

From the plot we can also see that our approach is

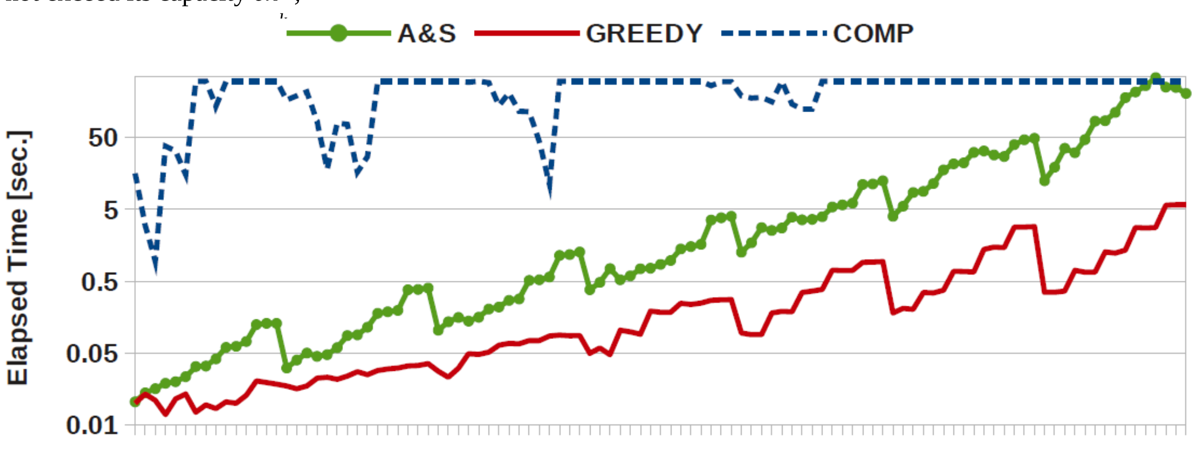

Fig.1 Average percentage of rescued victims.

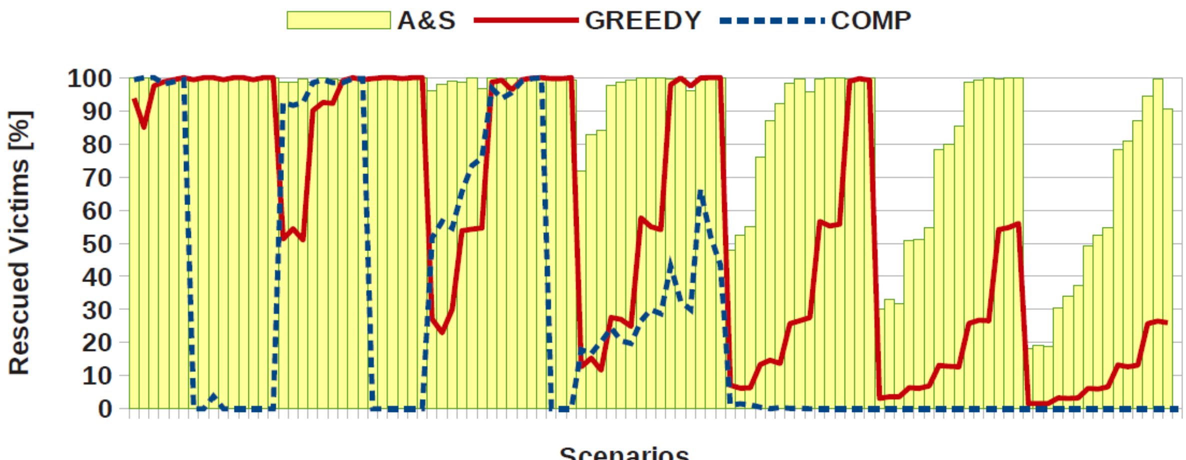

Fig.2 Average scheduling time.

especially better for scenarios involving a large number of victims. In particular, COMP algorithm can not find a solution within the timeout when the number of victims is greater than 128. It is therefore clear that this approach, although conceptually complete, is not scalable to large sizes. This can be a significant problem in scenarios like ours: it is not permissible to wait 5 minutes and having no solutions. GREEDY usually makes local choices that have a huge impact on the total number of the victims that could be saved. Although better than COMP for scenarios with many victims, the gap between GREEDY and A&S is significant. On the other hand, our approach in these cases tries to come up with a better global choice and therefore it can be far superior than a simple heuristic based approach.

In Fig. 2 we show the time needed to compute the entire schedule of the ambulances (please note the logarithmic scale). Although it is not surprising that GREEDY is faster while COMP is slower (the timeout expired often), it can however be observed that our approach takes reasonable times. In fact, in average the ambulances are allocated in 24.48 seconds, which means that on average in less than half a minute all the ambulances will be able to know the path that should be followed. Moreover, the median value indicates that for half of the scenarios the entire schedule is computed in less than 1.17 seconds.

Technical details. All the experiments were conducted by using an Intel® Core™ 2.93 GHz computer with 6 GB of RAM and Ubuntu operating system. The code for COMP and GREEDY algorithms was fully developed in Python. In particular, GREEDY algorithm exploits Gurobi [11] optimizer for solving the MIP problem and Gecode [12] solver for the COP problems. The code for the subsets generation is instead taken from [13]. Differently, for COMP algorithm we used Python for generating a MiniZinc [14] model solved by using the G12/FD solver of the MiniZinc suite. All the code developed to conduct the experiments is available at http://www.cs.unibo.it/~amadini/ijimai_2013.zip

V. Related Work

In the literature many techniques from operational research and artificial intelligence have been used to tackle different aspects of the disaster management problem. Most of the approaches are trying to develop and study pre-event solution to decrease the severity of the disaster outcome. As an example, in [15] the authors study the best allocation of deposits that allows to handle in the most efficient way the rescue operations in case natural disaster happens. In [4], the authors use MIP in order to schedule the operation rooms and the hospital facilities in case of a disaster. These paper however have a different goal from ours: we are not concerned with considering preventing measures that could allow to mitigate the consequences of future disasters. We are instead concerned with saving more victims, after the disaster happened.

There is also a large literature related to the problem of deciding the initial location of ambulances in order to decrease the average response time for ambulance calls. However, very few papers deal with the computation of the schedule for an ambulance. Some authors focus just on computing the best path for an ambulance toward the victim. For instance in [6] the authors use graph optimization algorithms in order to find a path for an ambulance. In our work we assume to have such a path and we are concerned with the problem of defining the order of the victims that an ambulance should pick up. In [16] the authors propose a routing algorithm for ambulances but, differently from our case, their model is probabilistic and it has been applied just for two small scenarios (*i.e.* scenarios containing few ambulances and victims).

In [5] the authors proposed the use of an interactive learning approach which allows rescue agents to adapt their preferences following strategies suggested by experts. The decision of the ambulance is based on a utility function incrementally improved through expert intervention.

Differently from our approach the authors here use an heuristic to dispatch the ambulances which rely on expert decision makers, while we rely only on optimization techniques.

In [17] is solved a task scheduling problem in which rescuing a civilian is considered as a task and the ambulances are considered as resources that should accomplish the task. The goal is to perform as many tasks as possible by using the Hogdson's scheduling algorithm to compute the solutions. Differently from our case, the authors considered here only the execution cost of the task and its deadline, ignoring important constraints such as the capacity of the hospitals and ambulances.

Combinatorial auctions are used in [18], [19], [20] to perform task allocation for ambulances, fire brigades and police forces. An ambulance management center is represented as the auctioneer while ambulances bid for civilians to save. Each free ambulance makes several bids and the auctioneer determines the winners using a Branch and Bound algorithm. A drawback of this approach is that it is difficult for bidders to estimate the cost for bids containing many tasks. Moreover, as pointed out in [21], if bidders bid on each and every possible combination of tasks the computation of satisfactory results is computationally expensive.

The authors in [22], [23] proposed a model based on a Multi-Objective Optimization Problem. They adjust controllable parameters in the interaction between different classes of agents (hospitals, persons, ambulances) and resources, in order to minimize the number of casualties, the number of fatalities, the average ill-health of the population, and the average waiting time at the hospitals. Then, they use Multi-Objective Evolutionary algorithms (MOES) for producing good emergency response plans. Their underline model is completely different from ours and we argue that is not very adaptable to deal with continuous changes and unexpected situations.

In [20], authors proposed partitioning the disaster environment in homogeneous sectors and assigning an agent to be responsible for each sector. Similarly, in [24], the city areas are partitioned and assigned to an ambulance. The number of clusters is determined by the size of the city. Such solutions could lead to unfair partitioning and inefficient assignment of agents to partitions. A more powerful partitioning strategy based on the density of blockades on the roads was used in [25]. This approach however requires a real-time information of the environment that is costly and sometimes difficult to retrieve.

Similarly to the GREEDY algorithm that we use as baseline, in [26] an heuristic is used to allocate the victims giving priority to the civilian with the highest probability of death. The shortcoming of this approach is that the cost of travel of the ambulance from one civilian to another could be very large; this could lead to a huge loss of lives if the size of the map is too large as in real-world situations.

In [27] Earliest Deadline First algorithm is also used to form coalition for rescuing victims. The victim with earliest deadline is selected and the number of ambulances needed to rescue this candidate in time is computed and called coalition. The use of coalition formation however works well when a task cannot be performed by a single agent, which is not the case for the task of saving a victim.

Finally we are aware of the existence of commercial applications for Emergency Dispatching (*e.g.* [28], [29]). The technical details explaining how these software are working unfortunately are always missing.

VI. Conclusions

In this work we have described a procedure that can be used as a decision support tool for a post-disaster event when a big number of victims need to be transported to the hospitals.

The proposed algorithm takes into account the position of the victims and their criticality, and schedules the ambulances in order to maximize the number of saved victims. Even though there is no guarantee that the solution obtained is the optimal one, experimental tests confirm that the number of saved victims is greater than the one that could be obtained by using, on one hand, a greedy priority-based heuristic and, on the other hand, a complete algorithm with a reasonable timeout of 5 minutes. Moreover, the proposed solution is usually fast enough to assign all the available ambulances in less than half a minute.

As a future work it would be interesting to evaluate our approach in a more dynamic and realistic scenario since assuming that the whole model is known a priori is not very realistic. A dynamic approach needs to adapt itself to context changes (*e.g.* new incoming victims, ambulances out of service, the critical state of victims, etc...).

In the event of significant changes the solution may be quickly updated exploiting the current allocation of ambulances without recomputing from scratch everything.

Moreover we would like to integrate the model with heuristics developed by domain experts.

Adopting these heuristics will allow the system to be able to react to a change very quickly, by using a default behavior that later can be changed if a better solution is found solving the optimiztion problem.

Another direction worth investigating is to study the performance and the scalability of the algorithm proposed taking into account also the robustness of the solutions (i.e. how the solutions vary depending on small changes of the initial model).

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Global Collective Intelligence in Technological Societies: as a result of Collaborative Knowledge in combination with Artificial Intelligence

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***Abstract* — The big influence of Information and Communication Technologies (ICT), especially in area of construction of Technological Societies has generated big social changes. That is visible in the way of relating to people in different environments. These changes have the possibility to expand the frontiers of knowledge through sharing and cooperation. That has meaning the inherently creation of a new form of Collaborative Knowledge. The potential of this Collaborative Knowledge has been given through ICT in combination with Artificial Intelligence processes, from where is obtained a Collective Knowledge. When this kind of knowledge is shared, it gives the place to the Global Collective Intelligence.**

***Keywords* — Collective intelligence, knowledge managenemt, artificial intelligence, intelligent systems, collaborative multimedia, ICT.**

I. INTRODUCTION

The inclusion of the Technology in normal live has meaning big changes in society. If ones can see to the past through ICT, in one minute could see: more than eleven millions of sending instant messages, more than fifty eight shopping web transaction, more than twenty thousand app downloads for mobile, more than six hundred and fifty new smartphone functioning, more than twenty four hours in video are uploaded in YouTube, more than three thousand tweets are sending, more than two millions searches in google and many more [1].

The use of ICT has been the key factor through the use of information and knowledge has introduced to society in the way to conform part of the Technological Societies. In fact, the European and Information Global Society report [2], talks about how new technologies, telecommunication and information has made an important global revolution which is comparable or even superior to the industrial revolution. In this new revolution, knowledge is recognizing as a technical factor that has made transformations in social, economic, political and institutional dimension.

As a result of this technological revolution and the network telecommunication advances has created a necessity to introduce new concepts and processes. The most important are collaboration, cooperation and sharing information and knowledge with the objective to give them an added value through acquisition, absorption, processing and communication of these elements [3]. This encouraged the introduction of two growth technical and economic factors which are innovation and investigation. That when both are enriched by continuous learning processes and once led to a global society forms a *Collective Intelligence*.

This concept is also directly linked to some dimensions of human development, such as: social, cultural, economic, political, technological and environmental. That produces institutional and plural perspectives changes in development of dynamism of the global society changes [4]. In fact, members of countries in the World Summit of Information Society[9] emphasize that the most important thing to consider is the commitment and desire to build a people-center society, focused in a global technological integration with an orientation to help and to a sustainable develop. Being important creation, search, use, and sharing of information and knowledge, creating a mutual participation on communities and people to help improve the quality of life [4].

II. DIGITAL AND COLLABORATIVE LEARNING

Every knowledge form inside Technological Societies in combination with the trend to collaborate and to share, shows learning as an important factor in the assimilation and transmission of an improved knowledge taking from information and knowledge received. Digital and Collaborative learning is superior than traditional learning in the way that a person can access and learn better from his own contents and the other people that share their more specific information and knowledge [5].

This create a sense of *global collaborative learning* where everyone has the same level to learn and to access to information in every place in the world, that means for

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example that an African young can access to the same knowledge that other young that is studying in the best university [6]. People from more collaborative environments learn more complex technological abilities with great facility and familiarity [7]. For this reason educative model built through more collaborative environments help to develop more creativity and potential in people which are growing up in more technicians environments [8][9].

This fundamental role of ICT in this new form of learning is based in a tendency toward "learning to learn" [10], that through adaptive methods and a greater appreciation of knowledge and collaboration between individuals [11]. It will be of great contribution to be transmitted, shared and especially compared to other thoughts, scientists and with Artificial Intelligence systems that process natural language, in the way to generate true global solution shared. These gradually improve the perception of complexity (in positive sense) of life in this Technological society.

One way to donate potential to this kind of collaborative learning is through the use of methodologies that strategically combine traditional learning techniques with new learning techniques based in new knowledge creation through Artificial Intelligence technics as intelligence tutorial systems that do processes allowing form an own strategy and molds as other Artificial Intelligence systems to learning needs. Being this interaction very propitious to conform the *collaborative learning* [12].

III. Collaborative Knowledge

There is no doubt that the best promoter of *collaborative knowledge* has been telecommunications networks. What at first had a useful of interchange and interconnection finally has being a space where collaboration between users and intelligent systems has become in a growing and daily trend. This is because adaptive learning of Artificial Intelligence through machine learning systems join with human learning has created a new model of collaborative learning based in cooperation between individual and devices [13], which helps to acquire and to build new knowledge giving potential development of new technologies and that helps to build a new *collaborative knowledge.*

At an organizational level this vision of a collaborative society allows the development of new knowledge in groups that function as knowledge production networks, which allows the creation of methodologies that encourage cooperative working form, assuming responsibility on self-learning and in knowledge transmission [14]. Thanks to connectivity this network society is itself a communication system globalized that have the capacity to join people from different cultures and languages through one and unique technological architecture [15].

Many tools used in this moment have been designed in a collaborative way, which aided by Artificial Intelligence processes such as intelligence systems, expert systems and recognition systems, based in knowledge engineering technics, obtaining a new assessment and dimension of this collaborative knowledge that is capable to increase technology experience [16]. Many of these tools have taken the development to a new way of perception of the new Semantic Web environment and App giving a way to the new construction of Cloud computing.

TABLE I
TRANSMISSION TYPE OF KNOWLEDGE

Knowledge element	Transmission Type
Individual Knowledge	One way
Collaborative Knowledge	Biderectional
Collective Knowledge	Bidirectonal
Cloud Contribution	One way
AI Contribution	Bidirectional

The thought called "knowledge paradox" says that according more knowledge is developed, it will lose its current value, therefore, it will be necessary creating new concepts such as *technological wisdom.* That means every new concept will be related with concepts in the ICT age based in a collective wisdom, and will be used to the growth of society [17], follow the way to the global technical revolution.

IV. Collective Knowledge

This technological age is expanding through combination of social, human and technological factors. Mainly through two purely intellectual processes: knowledge and intelligence. Where collaboration and cooperation in large scale, in union with interconnection that allows the interchange of these intellectual elements, conform a global network of knowledge, that are concentrate in form as a greater knowledge inside the *global brain* where the thought of every person works as a neuron and the synapses accurse through Artificial Intelligences technics as Bayesian networking and fuzzy logic, directly on the Cloud.

A scientific study of the Technical Institute of Massachusetts in EEUU, says that the more efficient work is "group work". That is because collective knowledge involves flexibility in allocating activities, and individual and group participation to give solution to problems. These allows the creation of a sensitivity social dynamic among team members. The result of these dynamics shows the existence of a collective intelligence as a joint ability, which is defined by the same ability of the individual intelligence and his relations with others [18].

This does not mean the discovery of collective knowledge concept, because it have already been used for long time in teams, however, is in the technological age, thanks to the Artificial Intelligence systems and ICT when it really started to have a real and potential meaning. Being the potential of this collective intelligence the creation of new knowledge networks [18], where an important element is the complexity that has arrived these knowledge networks as a collaborative system that interconnects equal intelligence and are implicated with sharing and developing of the new knowledge. This has changed the way to work in three types of knowledge networks: investigation, business and education [13].

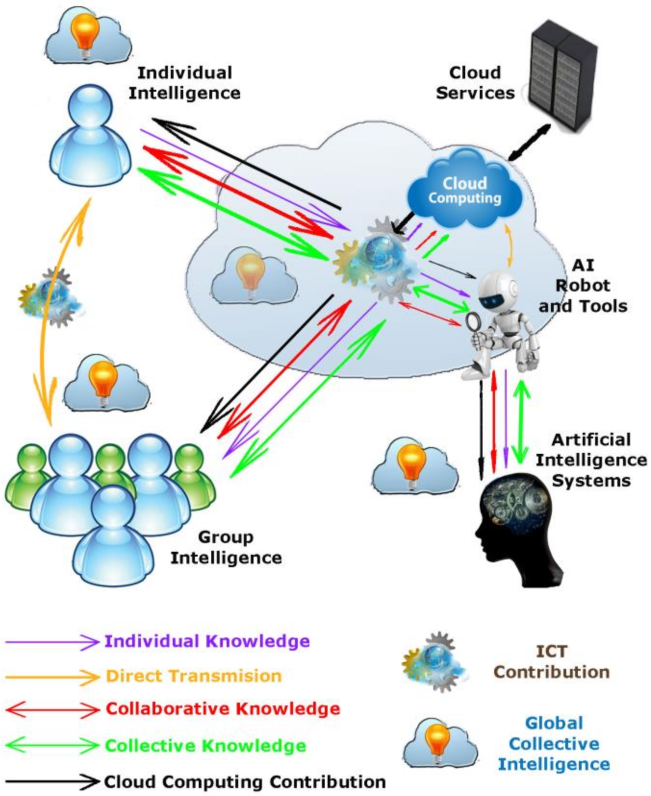

Fig. 1. Global Collective Intelligence.

Until few years ago, wisdom was concentrated and represented just by lone geniuses, but now it is represented and performed by collaborating people which sharing their knowledge arrive to an enriched knowledge that generated *collective intelligence*. That does not mean that there is no longer talented people and geniuses, but ICT evolution allows global participation creates the possibility of new developments, in short term, through this new technical-social element, as is *global collective intelligence*, which allows the creation of global and community wisdom [17].

All of these have transform human mindset from individual thinking to global thinking [20] which allows build a new intellectual level called *global collective intelligence.* These new kind of collective intelligence is giving by the direct relationship between normal collective knowledge processes with aids of Artificial Intelligence systems, in addition to ICT technologies [31].

V. Artificial Intelligence Contribution

Artificial Intelligence has been presented as a desire to get a better comprehension of human behavior through multidisciplinary information processes that involves complex aspects of own people cognitions and social processes that lead to acquire knowledge through collaborative processes [21]. Also the desire of imitate cognitive human behavior has made that in this half of century of application of Artificial Intelligence, it has passed from simple theories and assumptions to have intelligent systems that follow algorithms created from logical models. Which with the help of different engineering techniques increasing the resemblance of the complex human thought.

Inside of ICT field, Artificial Intelligence has contributed significantly in last years in conformation and concretion of virtualization tools that give a delocalization service in real time. For this it has become very popular the use of Cloud Computing [22], which allows to cover the necessities of software and web services demand through the Cloud, in a bigger scale and lower cost that invest in an own technical infrastructure.

The creation of a collaborative platform can helps to collective absorption of the risk and a greater flexibility to give effectively solutions to the market [23]. Cloud Computing has allowed developing of a digital economy, which has allowed organization to obtain a key element over global economy. This is to increase the competitiveness and other benefits as: improve demand attention on infrastructure and services, stimulating activity and guarantee sustainability, process optimization, creating new market opportunities, business stability, and return of investment, among others [24].

The interaction between business, society and Technology though the creation, use and storage of large amounts of multimedia information inside the *Big Global Data* [10], which will need more and more sophisticated Artificial Intelligence Systems and equipped with operational intelligence and data mining, which help to have a faster and personalized access to all information helped by knowledge engineering [25]. And likewise through intelligent agents it is possible to learn to recognize patterns to obtain suggestions from access information systems [26], which help to increase in collaborative knowledge and the growth in collective intelligence.

TABLE II
Artificial Intelligence Systems that Contribute to the Creation of Global Collective Knowledge

AI System	Field
Machine Learning	Automatic Learning
Tutorial Systems	Learning Help
Knowledge Engineering	Expert Systems Develop
Bayesian Networks	Networking Assignation
Computational Linguistic	Voice Recognizing
Natural language Processing	Communication
Data Mining	Data Exploration
Software Agents	Information Treatment
Fuzzy Logic	Decision-making
Operational Intelligence	Real Time Information Management

VI. Collaborative Multimedia Importance

In the past years, the arrival of mature has had both Cloud

10Big Global Data is a concept of a large global database.

Computing and Smartphone technologies have had a big influence in society. Which allowed to introduce agile changes enhanced by the large interconnection between people and technologies [27]. The combination of digital social media with the set of Artificial Intelligence techniques as a computational linguistic and natural languages processing, integrated in digital devices and app with transmission and communication networks have changed the way that people socialize. Relationships include a new compromise concept in communication [28], reflecting a better communication, comprehension quality and optimizing knowledge exchange [29].

Maybe it is here, where more Artificial Intelligence techniques as a software agents have been used to process all collaborative knowledge given by multimedia through tools as robots applied to the Cloud, expert and predictive tools that attempt to predict knowledge preferences, which joined with patterns recognized tools can suggest the best information options obtaining a more dynamic knowledge [30]. This helps to grow in a more *Collaborative Multimedia* experience that becomes more and more in a collective knowledge storage tool from which it is possible to learn in a global and collaborative way.

VII. Conclusion

The contribution received by the human elements as knowledge and intelligence, that have been maximize by ICT and their big influence in Technological Societies have begun to transcend human frontiers. The emergence and maturation of Artificial Intelligence has made human individual and collective cognitive elements creates and improves a new enriched knowledge. Which when it can be shared through communication network and processed by collaborative tools, generates an individual intelligence.

This individual intelligence sharing with others and transmitted as a Collaborative Knowledge and also process by Artificial Intelligence tools form a new Collective Intelligence that thanks to telecommunication networks becomes into a *Global Collective Intelligence.*

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PLANE: A Platform for Negotiation of Multi-attribute Multimedia Objects

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Abstract **- This work proposes the definition of a system to negotiate products in an e-commerce scenario. This negotiation system is defined as PLANE – Platform to Assist Negotiation – and it is carried in a semi-automatic way, using multi-attributes functions, based on attributes of the negotiated content. It also presents an architecture to interconnect the participant through an inter-network in the television broadcasters context. Each participant of the inter-network applies policies for its own contents, and all of them must comply these policies. If a participant needs a content not covered by the policies, it is possible to start a negotiation process for this specific content. Experiments present a simulation scenario where PLANE assists the negotiation between three sellers and one buyer with predefined negotiation profiles. Results demonstrated the success of the system in approximate the negotiator after some few interactions, reducing time and cost.**

Keywords **- e-commerce, negotiation, inter-network, multi-attribute, multimedia.**

I. Introduction

Currently television broadcasters produce and keep a large amount of audiovisual content that is distributed between their commercial partners [1]. However the distribution and trading of this material involve complex contractual negotiations between television broadcasters, like contracts signing, rights and duties establishment, are applied to the negotiated content [2]. Furthermore, the search and content acquisition from another broadcasters have have been prove a hard tasks, due a lack of an efficient infrastructure that provides means to broadcasters connect and negotiate their content.

In these circumstances, the definition of a negotiation system to share audiovisual content of television broadcasters with other partners is relevant, providing the means to negotiate the content, respecting the contractual policy established. More than that, the procedures of negotiation must be performed in a semi-automated way, in order to overcome the delay caused by negotiations made by people.

This work aims to define a negotiation system to share content by television broadcasters. To support it, a logical architecture to interconnect broadcasters was defined, creating an inter-network of broadcasters. Also within the inter-network it is possible to negotiate one or more audiovisual contents among two or more participants through the module called PLANE. This module considers attributes extracted from the content negotiated, like price, number of views and resolution, to generate offers and counteroffers in a negotiation session between two or more participants in the content negotiation.

In Section 2 are presented some related work in audiovisual content sharing and negotiation using a semi-automatic away. In Section 3 is presented the architecture to support the inter-network concept of television broadcasters and its services. In Section 4 the PLANE is shown, a mechanism for semi-automated negotiation of content in the inter-network. In Section 5, one scenario of negotiation with PLANE is presented together with results. In Section 6 the conclusion is presented altogether with ideas for future work.

II. Related Works

In [2], it was proposed the AXMEDIS framework to integration, production and distribution of digital content. The AXMEDIS creates a P2P network of digital content producers where content negotiation is possible through B2B or B2C.

In the context of negotiation the approach presented in [3], which is an extended work of [15], presents improvements related to the semi-automatic way of negotiation, such as the number of attributes considered in negotiation and the utilization of a formal rule to generate an offer proposal.

According to [16] many of the problems faced by [15] are solved, but it is limited to the use of static attributes in the agreements, not being possible to consider other attributes. Another approach was presented in [4], adapting the concepts of [5] to the context of that work: the use of multi-value functions and weighted attributes, where the latter represents the degree of relevance given by a negotiator. Besides these works, the work of [17] treats the negotiation using one or more attributes, but like [15], actually, the negotiation is made using only one attribute, in this case, the price

III. Broadcaster inter-network

Although it would be easily applied to any kind of product of an e-commerce context, as a case of study, this work focuses on audiovisual content negotiation and sharing through the definition of an inter-network of broadcasters, where the participants select and publish their contents to be shared and negotiated with other participants connected to the inter-network.

In the architecture proposed here, the connection with other participants of the inter-network are made through PCE (Point of Content Exchange). In a simple comparison, a PCE

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resembles a router, because it is located in the edge of the network, making the connection with other possible participants of the inter-network. Also the PCE is responsible for other functions, like the management of policies, shared content and the negotiation of some content published to the inter-network. Figure 1 presents the architecture of the PCE and its components.

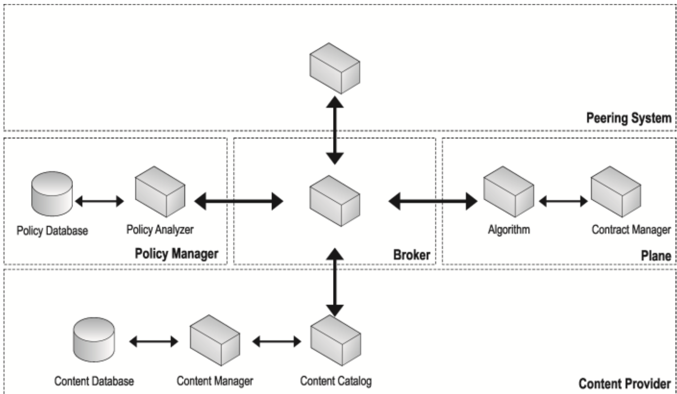

Fig. 1 - Point of Content Exchange (PCE) architecture

There are several metadata standards to deal with, like MPEG-21 [9], PBCore [10], TV-Anytime [11], making integration of DAM (Digital Asset Management) systems a complex task, because it is necessary to understand the semantics of the attributes defined in metadata, to make consistent relations between two different metadata standards [7].

The Negotiation System is the focus of this work. In this component occurs the effective negotiation among two or more participants of the inter-network. The negotiation module is called PLANE (PLatform to Assist NEgotiation), which is composed by a Contract Manager and an algorithm for negotiation. The components of a PCE are described as following.

A. Peering system

The Peering System is responsible for managing the connections of the PCEs in the inter-network. It includes the discovering of other PCEs, the establishment of connections and selecting which connection each data flow (search, negotiation, control, contracts, etc.) uses.

Thus, the Peering System establishes and maintains the topology of the inter-network, i.e., it defines an Internet television network, established in application level under an existing distribution infrastructure such as the Internet. Therefore, the inter-network is an overlay network that performs application-level infrastructure over a physical communication [19].

B. Broker

The Broker is responsible for controlling the information flow between the components of the PCE, dispatching requests from the Peering System, receives requests to verify of policies, access content from a particular participant, transmitting necessary attributes in a negotiation, and so on.

C. Policy Manager

The Policy Manager role is to define and validate the permissions established by the participants of the shared contents in the inter-network. For example, a policy can be defined to a particular content does not appear in a search result made by other participants in the inter-network.

Policies are defined using a specification language called XACML [8]. The manager of the broadcaster choose the content that will be shared in the inter-network and adds a standard policy for the content being made available. A standard policy deals with the actions that participants can perform with a shared content, without necessarily start a negotiation. For instance, a policy can state that any participant in the can view a particular audiovisual content, but only the low quality version. If a high-quality version is more suitable, the content holder should be contacted for a direct negotiation.

D. Content Provider

The Content Provider is responsible for performing the integration and management of content provided by each broadcaster participant in the inter-network. This integration is necessary because each broadcaster has its own system of asset management [19], which may have different metadata standards, video formats and other features for multimedia storage [20][23].

Thus, the shared content are categorized in a standardized way to facilitate traffic information in the inter-network. To this catalog new attributes can also be added, as the price of a given content, information that is relevant to the trading system.

E. Negotiation system

In this component occurs effectively the bargaining between two participants in the inter-network: one in the role of seller and the other as buyer of the shared content. It consists of a Contract Manager and an algorithm for negotiation. The algorithm analyzes and creates new bids, does counter-offers and effectively conducts the negotiation of digital content between the two participants. This negotiation starts only when any participant is interested in buying a specific content of one of the other participants. This content would not be available directly because of some restriction in default policies that were initially established by the Policy Manager.

Once the negotiation is made, the Contract Manager is responsible for defining the contract in XML, concretizing this negotiation. This contract template is a generic XML, so it can be exported to other contract models, using a Rights Expression Language (REL). For this study we used the ODRL (Open Digital Rights Language), due to the fact it is an open-source language, community-supported, flexible and extensible. It was developed to express licenses on digital objects in a value chain of producers, distributors and consumers, adding security and control over the negotiated content [21].

So far, we describe an architecture for interconnecting television broadcasters in order to create an inter-network, where it is possible to integrate content from broadcasters, policy specification for sharing these contents and the mechanisms for negotiation between participants of different contents. The next sessions will be focused on the negotiation system called PLANE.

IV. PLANE

For negotiation effectively occurs, it was developed an algorithm that is responsible for generating a set of offerings and counter-offerings, where its main goal is an agreement that brings gains for all parties involved in the negotiation. To understand the operation of the algorithm, prior knowledge of some concepts is necessary: what is an attribute, multi-attribute functions and the weight given to an attribute.

According to [12], attributes can be defined as the characteristics of a product. They can be concrete, observable or measurable of relevant importance. Another more general meaning is given by [13], which defines the attribute as a characteristic qualitative or quantitative of an observed member, in other words, each property that defines an object or entity. The algorithm presented here will focus only on quantitative characteristics.

The negotiation decision can be weighted by a single attribute, but situations like this are not as common. The most frequent problems require the measurement of more than one attribute [14].

The weight corresponds to the degree of importance that a negotiator (buyer or seller) defines to the attribute. It is a value in the range from 0 (least important) to 1 (most important). However it could be any other continuous range (with values belonging to the set of real numbers) that can be transformed into a percentage scale.

A. Functions

According to [4], the usage of Value Functions and Utility Functions is necessary for a negotiation tool to formulate possible decision options, where both specify a unique structure of preference. The Value Functions are a particular case of a Utility Function and is embedded in an environment of certainty; a Utility Function can also handle systems involving an environment of luck. In this paper, it was considered only Value Functions. The negotiation process also considers more than one attribute, so here functions with multi-attribute values are used. With this type of functions, it is possible to manipulate the impact of changing attributes throughout the process, making the negotiation flow faster and more efficient.

According to this criterion, three functions were used: a Linear Function, the Total Value Function and the Displacement Function, all adapted to our scenario. The functions are shown as following.

4.1.1. Linear Function

The Linear Function is used to normalize the different kinds of values for the attributes and is defined as:

$$Linear = \frac{AVw - AVd}{AVw - AVb} \qquad (1)$$

Where:

AVw → Worst attribute value
AVb → Best attribute value
AVd → Desired attribute value

4.1.2 Displacement Function

One of the challenges of this work was to define how much the algorithm would spread the values of the attributes to launch a new bid into the interval initially defined by the negotiators, aiming always to present an better bid than the offered before. The Displacement Function was based on the model of [3] and is defined as following:

$$Fd = |(AVb - AVw) * (1 - \alpha)| \qquad (2)$$

Where:
AVb → Best attribute value
AVw → Worst attribute value
αi → Weight of attribute

4.1.3 Total Value Function

After normalization of the attribute values, the function defined by [4] was used, called Total Value Function (FVT), which is defined by the sum of the Value Function (here is the Linear Function) of each attribute multiplied by the weight of each attribute. The FVT is presented as following:

$$F_{vt} = \sum_{i=1}^{n} \alpha_i F_{linear}(i) \qquad (3)$$

Where:
i → Content of attribute
αi → Weight of attribute
F_{linear} → Linear Function of the attribute

B. Offer Validation

Using the mathematical concept of combinatorics, the algorithm is able to generate new offers to be proposed to the buyers. To do this, the algorithm uses the offer that is desired by the sellers as base to perform variations and then generated new ones to the buyers.

As stated before, content can have several attributes, which can be classified as qualitative or quantitative. To generate a different offer, there must be a variation of at least one of the possible attributes of the content in negotiation.

Before performing a variation in an offer, it is necessary to know how much could be that variation of an attribute in a negotiation. To do so, it is necessary to calculate the Displacement Function. In our scenario, it is considered three attributes, generating 27 combinations of variations of these attributes to be processed and suggested to the participants of the negotiation.

Finally, a validation is still necessary, because the algorithm needs to generate an offer that is within the limits and interests of the buyer. As soon as an offer is generated, an analysis is done to ensure that all the offers fit the buyer's needs.

V. Experiments

The simulation described in this section analyzes the feasibility of the negotiation algorithm with different amounts of buyers and sellers. To validate the algorithm, we developed a scenario composed of three sellers and one buyer. In this scenario, the negotiation was divided into three separate negotiations between one buyer and one seller. Suppose one negotiator wishes to purchase a video related to the final match of volleyball of the Olympic in Athens, 2004, in order to conduct a retrospective and make a comparison with the actual team, which will compete in the Olympic Games of Rio, 2016. The initial offer of the negotiator was to buy the media and its broadcasting rights by $500, with permission to exhibits it 13 times with a resolution of 720p (resolution of 1280x720). Lastly, the negotiator was configured as a *hard negotiator*; in other words, he is very conservative and seeks a counter-offer very close to what he defined initially. Tables 1 and Table 2 show the settings used for the buyer and the sellers, respectively.

TABLE I
CONFIGURATION OF THE BUYER FOR THE NEGOTIATION

Attribute	Worst value	Best value	Desired value	Weight
Price	$650	$480	$500	0.5
Exhibition	10	20	13	0.3
Resolution	720p	1080p	720p	0.2

TABLE II
CONFIGURATION AND EVALUATION OF THE SELLERS FOR THE NEGOTIATION

Seller	Attributes	Worst value	Best value	Desired value	Weight	Total Value Function
	Price	$700	$500	$600	0.6	
1	Exhibition	12	24	13	0.3	0.266
	Resolution	480p	720p	720p	0.1	
	Price	$600	$480	$480	0.5	
2	Exhibition	9	19	10	0.3	0.494
	Resolution	480p	720p	720p	0.2	
	Price	$640	$500	$550	0.4	
3	Exhibition	13	21	16	0.4	0.601
	Resolution	480p	1080p	720p	0.2	

Still considering this scenario, it was made another setting in algorithm to generate 20 new valid counter-offers. However, this will occur only in the best case, and in the worst case, no bid may be generated if the counter-offers are off the determined range by the negotiators. Counter-offers whose values do not exceed the limits proposed by the negotiators involved and are within the percentage of the selected profile by the buyer are considered valid. The valid counter-offers are sorted in descending order, in relation to the difference between the Total Value Function of the sellers and the buyer. Table 3 shows the top five offers generated for each seller participating in the negotiation.

TABLE III
TOP FIVE OFFERS GENERATED BY PLANE

Buyer	Offer number	Price	Exhibition	Resolution	TVF	TVF differ.
	1	$595	14	720p	0.512	17.2%
	2	$500	13	720p	0.725	17.0%
1	3	$505	13	720p	0.712	15.0%
	4	$510	13	720p	0.700	13.0%
	5	$590	15	720p	0.550	11.2%
	1	$498	19	720p	0.894	44.4%
	2	$496	18	720p	0.886	43.1%
2	3	$494	17	720p	0.878	41.8%
	4	$492	16	720p	0.870	40.4%
	5	$490	15	720p	0.861	39.1%
	1	$525	16	720p	0.558	9.8%
	2	$520	16	720p	0.572	7.5%
3	3	$515	16	720p	0.587	5.2%
	4	$510	16	720p	0.607	2.9%
	5	$550	19	720p	0.637	2.8%

Only offers 4 and 5 of Seller 3 are valid. This is evidenced by the percentage obtained by these two bids, since they are lower than the percentage of the buyer profile, which is considered hard with acceptance of 5% variation. Table 4 presents a summary of the negotiation between the Buyer 1 and the sellers after the execution of negotiation by PLANE.

TABLE IV
SUMMARY OF THE NEGOTIATION BETWEEN THE BUYER 1 AND THE SELLERS

Buyer	Offer number	Price	Exhibition	Resolution	TVF	TVF differ.
	1	$600	20	720p	0.649	0.030
1	2	$480	10	720p	0.494	0.005
	3	$510	16	720p	0.607	0.012

For Seller 2 was maintained the offer before the execution of the algorithm. The counter-offer presented to the Sellers 1 and 3 were generated by PLANE, showing improvements, enabling greater probability of agreement between Buyer 1 and the sellers.

Finished this scenario, it is evident that from a negotiation with one buyer and N sellers, it is possible to generate offers for all parties involved individually. Eventually, the Buyer chooses among the offers generated by the three sellers, according to its judgment.

A. Scenario Analysis

The simulation scenario showed that the PLANE was able to generate new counter-offers for the negotiation, either one to one (1-1), one to many (1-N) or many to many (N-N), after performing the necessary transformations. In the simulation scenario, the generated counter-offers were more improved rather than the offers presented initially. As the algorithm is semi-automated it does not make decisions with respect to the negotiation closing, it is up to the Buyer choose with which seller he close the negotiation. Figure 2 shows the prices and the number of rounds necessary for the generation of the new counter-offers to all involved sellers.

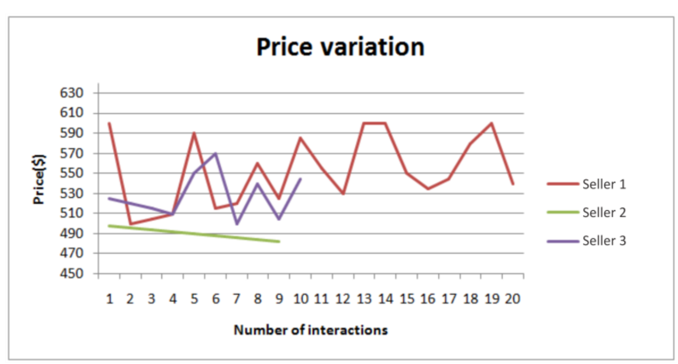

Fig. 2 – Price variation during negotiation

For Seller 1, despite being generated 20 valid negotiations, the chosen offer maintained the previous values for the price and resolution, which were $600.00 and 720p respectively. The only attribute changed was the amount of exhibition, from 13 to 20, taking 13 interactions to find a counter-offer within the selected profile. For Seller 2 the offer was maintained as previous one, since the PLANE failed to obtain improvements over the original offer. For Seller 3, who originally asked $550.00 for the rights to exhibit the videos, achieved a reduction of $40.00, closing the negotiation for $510.00. The other attributes were maintained with its initial values. Figure 3 presents the values for the Total Value Function before and after execution of PLANE.

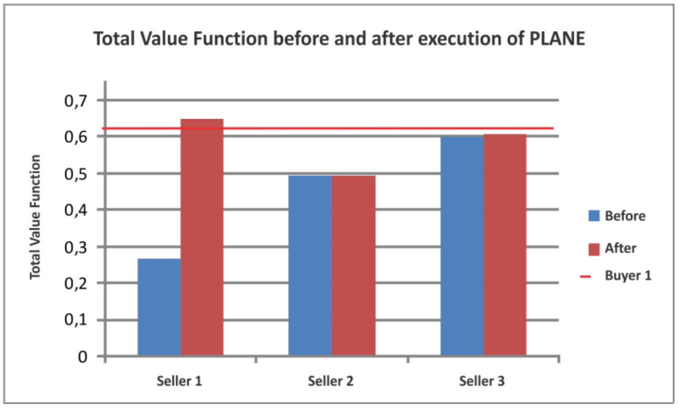

Fig. 3 - Total Value Function before and after execution of PLANE

It can be observed from Figure 3 that further approximation of the FVT value of sellers with the buyer was 0.619. For example, the Seller 1 had FVT 0.266 before negotiation, with a difference of 0.353 to the Buyer, after negotiation this difference dropped to 0.03. For Seller 2, the algorithm did not achieve improvements. In contrast, for Seller 3, the difference decreased from 0.018 to 0.012. In the end, the Buyer might choose with which seller he will close the deal. Thus, the PLANE brings together the interests of the negotiators involved, even selecting the profile of a hard negotiator. In practice, PLANE can reduce the negotiation time, even when the deal is not directly closed, always bringing the negotiators to offers that somehow benefit all of involved.

VI. Conclusion and Future Works

This paper presents an extension of a proposal for a negotiation system that was applied for audiovisual content (see [22]). This negotiation system is implemented in a semi-automated way, using multi-attribute functions and quantitative weighing of attributes to better negotiate the terms of a possible deal. Using PLANE can bring some advantages such as reducing the time to reach an agreement, semiautomatic negotiation allows for multiple participants. Sometimes the algorithm fails to generate valid offers or there may be biased depending on the values added to the product attributes in negotiation.

As a future research the use of other multi-attributes functions in order to increase the efficiency of the negotiations is being investigated. Furthermore, how to choose the attributes dynamically at the time of negotiation is also being investigated, giving more freedom for both buyer and the seller.

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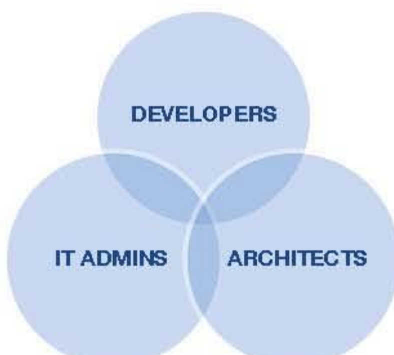

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