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Towards a Simulator of Integrated Long-term Care Systems for Elderly People

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In this paper, we propose a simulator for integrated long-term care systems using as a starting point a holistic model of care systems for people that need long term care, the Sustainable Socio-Health Model (SSHM). The implementation of the simulator on the Jason multi-agent platform allows the tool to include the human interactions, preferences, and social abilities that take place between elderly people and the staff of healthcare systems (doctors, social workers and nurses). In addition, the use of this multi-agent platform provides the required scalability for simulating population sizes of different orders of magnitude. The paper shows the model to be implemented in the simulator, the simulator architecture, the types of agents considered, their functionality and the information flow among them. Additionally, it shows the validation of the simulator with real data obtained from empirical studies conducted by the Polibienestar Research Institute in Spain, as well as a performance evaluation that sketches the performance of the simulator when using the centralized Jason infrastructure under different population sizes. Effectively, simulation can provide policy makers with the option of going into a decision theatre and virtually knowing the consequences of different policies prior to determining the real policy to be adopted.

Keywords: Multi-agent based simulation; long term care; social sustainability; elderly people.

1. Introduction

Two of the most important systems of European public welfare, social services and health systems, operate in parallel but in an uncoordinated manner with different assessment systems, training, and professional cultures. This leads to ineffectiveness and inefficiency, having a negative effect on both the quality of life of elderly people and state budgets, which will be unable to stop public expenditure in these protection systems.[1] In this sense, some holistic models of care systems for people that need long term care have been proposed.[2,3,4,5] These models aim not only to increase the welfare and quality of life of elderly people, including dying with dignity, but also to perform a joint reorganization of health and social systems, in such a way that they can provide integral services to elderly people with a lower cost. Among the existing models, some studies have shown the many positive features of *case management* methodology[6,7,8] with respect to other methodologies.

However, the use of these models at different scales can have long-term effects in different healthcare systems. In this sense, the European Commission has recognized the complexity in deciding health policies to assist people who require long-term care without knowing its consequences in the short, medium and long term.[9,10] In order to estimate these effects and determine the benefits or disadvantages of different long-term care policies for elderly people, the use of Information and Communication Technologies (ICT) simulation tools becomes necessary. Effectively, computer-based simulation tools can provide policy makers with the option of going into a decision theatre and virtually knowing the consequences of different policies prior to finally determining the real policy to be adopted. In this way, the prediction of impacts of healthcare and social welfare policies would be greatly improved. There were many positive features of case management methodology that were highlighted by these studies.

In this paper, we present a computer-based simulator for integrated long-term care systems for elderly people. This tool simulates the Sustainable Socio-Health Model (SSHM),[3,4] a holistic model based on case management methodology developed for the people that need long term care in the Valencian region (Spain), and it consists of a multi-agent based system developed using the *Jason* multi-agent platform.[11] The main reasons for choosing the SSHM among other models is that on the one hand it is a representative example of the case management methodology, and on the other hand that there exists an experimental study testing the real benefits of SSHM on a real system, whose results can be used to validate the simulator results.[5] The implementation of the simulator through multi-agent systems allows the tool to include the human interactions, preferences and social abilities that take place between elderly people and the staff of healthcare systems (e.g. doctors, social workers, psychologists, nurses, etc). On the other hand, the use of a general purpose multi-agent platform such as Jason, that includes a distributed infrastructure capable of taking advantage of distributed computer architectures, allows the tool to easily become scalable, in order to simulate different orders of magnitude in the population size. The paper shows the simulator architecture, the types of agents considered, their functionality and the information flow among them. Additionally, it shows the validation of the simulator with real data, as well as a performance evaluation that sketches the performance of the simulator when using the centralized Jason infrastructure under different population sizes. The performance evaluation results show that the tool can simulate long-term care systems for large populations within a few minutes by using a single standard computer platform and the centralized Jason infrastructure. Taking into account that the simulation of long-term care systems is an off-line task without timing constraints, these results guarantee the scalability of the simulator with the population size to be simulated.

The rest of the paper is organized as follows: Section 2 shows the related work about modeling long-term care systems for elderly people and multi-agent systems for simulating healthcare systems. Next, section 3 describes the SSHM as well as the translation of this model to a computational model that can be simulated on a computer through a multi-agent system. Section 4 presents the implementation strategy, the multi-agent platform selected for the implementation, and the main details of the simulator of integrated long-term care systems for elderly people. Next, section 5 shows the validation of the simulator with real data, as well as the performance evaluation of the simulator itself. Finally, section 6 shows some conclusion remarks and future research work to be done.

2. Related Work

2.1. *Modeling healthcare systems*

The differences in service infrastructures, qualitative problems in home care and discharge practices are common in many EU-countries. For example, there are significant differences with respect to shortcomings in the flow of information, with respect to the continuity of care between hospital and home, and also with respect to the connection between health and social care.[7,12] In addition, there is a lack of clarity concerning responsibilities for patients after discharge from hospital to home care and a lack of integration of services based on the patient needs. Furthermore, hospitals have increased their efficiency in terms of reducing the average length of stay.[13] As a consequence, older people become frail when being discharged, thus increasing the risk of re-admissions if there is a lack of community care services. Frail older people are therefore a target group that calls for special attention when planning and implementing hospital discharge management, community health facilities or home care services after a hospital stay. Appropriate service packages should contain multiple services provided by different stakeholders.[14] New discharge and home care practices such as case management and multidisciplinary team work have been developed to address the above mentioned shortcomings and also to cut or restrain the costs of health and social care.

Perhaps the most common innovation in job profiles has been the development of discharge managers whose task consists of facilitating the transition between hospital and home care services.[15] In France, for instance, a medical doctor may obtain the status as a coordinating physician in care homes following relevant training. In Finland, case management methodology has been used to improve home care and discharge practices.[6] In that case, the *case management*[6] is familiar with the patient and informal caregivers, as well as with the service organization in general. With support from the multidisciplinary team it is able to effectively integrate the various health and social services as well as informal caregivers support. By offering adequate care and services at the right time it is possible to prevent or at least slow down the deterioration of clients functional ability (FA) and health-related quality of life (HRQoL) and to improve care efficiency.[6] The Swiss Kompass project[7] has approached the concept of case management similarly to the SSHM by creating interdisciplinary teams consisting, in this case, of five professionals (i.e. 2 psychiatric nurses, 1 psychologist, 2 social workers). New pathways and care processes have also been created in other countries, for instance in France during the COPA project.[8]

There were many positive features of case management methodology that were highlighted by these studies. First, the structure (care team, case managers) and processes of care (team work, need of assessment, transfer of information, coordination) were improved to achieve a better integration of services and, as a consequence, more appropriate care for patients/users at less cost. Second, the different models based on case management methodology proved that detailing the patients care and service networks can reveal obstacles in the care chain that can be overcome to improve current practice.

In Spain, the Sustainable Socio-Health Model (SSHM) was proposed to provide new pathways for older people with less cost. This model is based on the previously proposed concept of 'social sustainability',[16] and it was developed by using case management methodology to link the network of health and social resources with the support of a multidisciplinary team.[5,17] The SSHM contributed not only to decrease the use and cost of services but also to improve the integration of health and social care for older people in a Mediterranean Welfare State scenario. The basic hypothesis of this model is that it is possible to improve efficiency in structures and processes from different systems, decreasing the overlapping work, by avoiding unnecessary re-admissions and by improving the patient quality of life at home. In order to achieve such improvements in structures and processes, a case management methodology with multidisciplinary team-work was applied, designing personal care pathways supported by social and health services.

2.2. *Simulating Healthcare Systems*

The optimization of healthcare systems both from the temporal and economic points-of-view involves the simulation of administrative and assistance processes. Currently, it is still an open issue which type of simulation is best suited to healthcare systems modeling,[18,19,20] being the main options the Discrete Event Simulation (DES), System Dynamics (SD), and more recently Multi-Agent Systems (MAS).

Discrete Event Simulation (DES) has been widely used in modeling health-care systems, and over the last 30 years several significant reviews of DES papers have been published.[18] DES mainly focus on modeling patient flows through hospital facilities, which is close to our scenario. The modeling of all the activities carried out in a hospital has not been developed yet, possibly due to the difficulty associated to deal with all the hospital activities within a single simulation model.[20] A straightforward solution generally adopted is to reduce the scope of the simulated domain, and in this sense, accidents and emergencies (A&E) units seem the most popular area for simulation modeling, since they are self-contained units and have easily observable processes during relatively short time periods. Thus, almost every year the Winter Simulation Conference proceedings include one or more papers on A&E simulations,[18] and there are numerous examples of papers focusing on this topic.[21,22,23,24]

Some authors have compared the use of DES and SD in health care.[25] They conclude that SD models are not well suited to detailed modeling, and they cope rather badly with stochastic variation, which is an important issue in the demand of emergency healthcare. In this sense, previous work had already tried to explain why DES is more useful than SD techniques[26]: the need for an individual patient focus, the importance of resource constraints, the primacy of clinical decision process, the power of animation and visualization for communicating with users, and the more realistic representation without restrictive mathematical assumptions.

On the other hand, System Dynamics (SD) has gained a wider acceptance in the simulation of mainstream health systems.[19] Some authors have developed a SD model similar to ours in which they investigate future demand for social care services in a UK region from elderly people.[27] The aim of this model is to explore the significant challenges of an aging population (in the context of budget limitations) over the next five years, and to explore the effects of two possible interventions (new policies) to meet these challenges. However, the best known SD models for social care in the UK have been developed by a consultancy firm, the Whole System Partnership (WSP).[28] These models have not been published in the academic literature, but full details can be found on the WSP website (www.thewholesystem.co.uk) and also as case studies on the MASHnet (2012).[29] One of these models was designed to review and explore different local reablement services[a] (in terms of both capacity and service models) and another one was developed to assist local authorities in implementing the UK's National Dementia Strategy for their own population.

Most of SD models take a "whole system" view, which is one of the key strengths of this simulation method, that offers a high level of aggregation. Typically, SD models are not designed to yield exact numerical predictions, but to allow stakeholders to learn about their system and explore policy options by investigating the knock-on effects of different interventions.[30] In order to model complex simulation scenarios, system dynamics have been also used in qualitative maps to help to identify new strategies and to facilitate the analysis and discussion in a logical structured way on a map.[31] Curiously, by doing so the SD model built seems to be approaching a typical DES scheme.

Finally, agent technology has emerged in the last years as a new and promising paradigm focused on the modeling, design and development of complex systems,

[a]Understood as means of promoting independence, providing personal care, help with daily living activities and other practical tasks.

and they have been used in many different areas.[32,33,34,35,36] In health care real scenarios, it is very usual that the knowledge and data required to solve a problem are spatially distributed in different locations, which adds several constraints on the planning of coordinated actions. Furthermore, the provision of health care typically involves the coordination of several individuals (e.g. nurses, carers, social workers) with different skills and needs. Additionally, they are usually located at different places and usually lack the supervision of a single centralized coordinator.[37]

Multi-agent systems allow to model in a realistic way complex, heterogeneous and distributed systems and environments, by assigning an agent to each entity involved in the real-world environment. MAS have become nowadays a good alternative for improving the performance of the medical simulated scenarios in terms of interoperability, scalability and reconfigurability. In this sense, classical computation paradigms fall short when trying to model an environment with such a variety of users and complex processes and interactions.[38]

From a computational point of view, planning and resource allocation represent areas in which the characteristics of agents-based solutions best fit.[39] In these areas many entities are modeled, ensuring a rich inter operation in order to execute efficient plans. Communication and coordination tasks are extensively exploited in these kinds of systems through the high level protocols included in agents (i.e. requests, queries, different kinds of negotiations, call for proposals, auctions, etc.). Agents also use a common terminology in the form of an ontology used to represent message contents, and therefore they may be considered as a very suitable basis to develop systems which faithfully model real communicative processes.

There are many examples of MAS systems for modeling different health systems. Some representative examples are the K4Care system,[40] aimed to represent the coordination between different health care partners, or the Domino framework,[41] an open proposal designed to create smart DSSs using BDI agents. A part of the framework is designed to react to general inputs (signs and symptoms) and the other part is designed to observe the consequences of those actions and adapt the current management. Other proposals[42,43] show the representation of healthcare systems through intelligent software agents.

A very recent review of the MAS technology applied to healthcare briefly summarizes those MAS which have been applied in real settings, such as hospitals or medical organizations.[37] The first example is CARREL, which includes different kinds of agents as surgeons (who formalize the requests for organ transplants), analyzers (who validate all the parameters according to the patient's data) and other kinds of agents. The simulated scenario introduces negotiation among agents to achieve a transplantation plan. In addition, a Database Agent stores all details related to the assignment of pieces, as the regulatory norms mandate.[44] The second example is a research project focused on the deployment of multi-agent systems for solving planning problems in health, Medical Information Agents (MIA).[45] In this example, the MAS performs the planning of the diagnostics, surgeries and hospital beds. At any moment, the chosen treatment can change based on a new diagnosis, and planned treatments can be re-scheduled due to emergencies. The main goal of this project is to design a multi-agent system that achieves a more efficient planning in this very dynamic environment.

Beyond the methodology used to implement the simulation models, all of them are built in order to help in the decision making process, but unfortunately many of them have not been finally implemented nor validated. Although simulation analysts can generate quick solutions, the time spent in collecting and analyzing the necessary input data is generally too long. Furthermore, the model validation represents another time consuming task, since many real data needs to be gathered. Since timing may be crucial for the healthcare decision makers, the required response time may add a hard constraint to the execution time required by the simulation tool. On the other hand, both the models created and the simulator that reproduces these models must be calibrated and validated (using real data) to ensure that they have captured the behavior of the real scenario that they are reproducing. Only after that validation stage the simulator can be considered as a useful application to help policy makers to test new policies. In this paper, we present both the simulator that reproduce a previously validated model, and the validation of the simulator itself by using real data.

3. Sustainable Socio-Health Model

The Sustainable Socio-Health Model (SSHM) consists of a joint reorganization of health and social care services to respond to people requiring long-term care.[3,4] This model is based on three principles: social sustainability, quality of life and dignified dying, and social co-responsibility. These principles include the criteria of sustainable health care in terms of affordability, quality, appropriateness and accessibility.[17] The model focuses, among other things, on the creation of case management teams and the implementation of new care pathways with the aim to achieve significant savings and efficiency in the healthcare system.[5] It monitors new care pathways in primary care systems to improve the efficiency of social and health care for elderly people with LTC needs through the case management methodology. The target group is, thus, the older patients (aged 65 or more). Several professionals are involved in forming a multidisciplinary team: a doctor, a nurse and a social worker. The team receives relevant training on the use of referral protocols, resource management and the use of assessment tools.

Concretely, the SSHM is composed of three elements: patients, health professionals (screeners), and the case management team. Patients are the target population of this model. One of the main purposes of the model is to improve the health and well-being of patients. The health professionals (screeners) are those professionals in the healthcare systems that first interact with patients, and are the ones in charge of analyzing (by means of screening tests) the suitability of a given patient for the SSHM. Finally, the Case Management Team (CMT) is the committee that will design a personal pathway for each suitable patient.

The SSHM operates with the steps and interfaces: when a patient visits the primary health center (either for periodic or aperiodic treatments), any of the professionals (doctor, nurse or social worker) analyzes the suitability of that patient for entering the SSHM, by means of several screening tests. If the patient is not suitable, then he/she is kept into the conventional healthcare system. However, if the health professional finds that the patient is suitable for the SSHM, then he is led to the CMT. In this case, the patient and his/her caregivers are assessed at home by the case management team.

Following the health and social assessment, the team designs the care plan. Although the CMT informs the doctor, nurse and/or the social worker who had previously dealt with the patient about the programme with the pathway proposal, the direct interaction with the patients participating in the project is carried out by the CMT.[5] Following, the resources are activated and the intervention started. The team monitors the process and becomes the reference point for both the patient and the caregivers in relation to all administrative processes. At the last step, the patient is discharged of the programme of case management after a determined period of time. At that point, the patient is admitted in a nursing home for elderly, he/she moves to another house or he/she passes away. The procedure until this phase lasts for about 6 to 9 months.

3.1. *SSHM evaluation on real population*

The SSHM was evaluated on a real health system in Spain.[4] The concrete municipality of Burjassot (in the province of Valencia, Spain) was selected for this study. In the primary health center of Burjassot, 152 older patients were taken for the evaluation of the SSHM, of which 101 were randomly assigned to the intervention group (receiving case management) and 51 to the control group. The sample very much reflected the situation of the total population.

The inclusion criteria for each of the participants were: patients aged 65 or more years, referred by doctors, nurses or social workers of the primary health care, using a referral protocol. The patients needed 15 points or higher in social discriminators and 10 points or higher in the health discriminators. Patients were excluded if low scores on the referral protocol were obtained, or if some psychiatric diagnosis or dementia existed.

Patients data were obtained from patient interviews at home (first week and after 6/9 months), medical and social records, and care registers. For example, the diseases were assessed according to the International Classification of Diseases (ICD-10),[46] the functional ability (FA) was assessed through Barthel tests, [47] and Caregiver Burden was assessed using Zarit Burden Interview.[48]

The validation period of the SSHM expanded along 9 months, and the results and findings obtained in this study were that more than a quarter of patients could be supported better and/or more cheaply through community care services, rather than by a hospital stay. The study identified 33 possible packages of services (pathways), and it decreased the use of acute care hospitals and increased the use of social resources such, personal or domestic care, remote care or day centers. The exclusive use of health care resources was lower in the group of participants in the case management programme than in the control group.

The results supported the basic hypotheses: care efficiency improvement and unnecessary hospital stays were reduced and patients needs were satisfied more appropriately by referring them to other, less costly services that provide equal or better quality of life.[3,4] Similar findings have been found in other European projects using case management as a method to overcome bottlenecks at the interface between health and social care services.[6]

4. LTCMAS: Long Term Care Multi-Agent Simulator

In this section, we describe the implementation of a multi-agent simulator that allows to run the Sustainable Socio-Health Model (SSHM) described in section 3 on a computer system and to analyze the results obtained from its application.

4.1. *Implementation strategy*

The purpose of our research is to develop a simulator of the SSHM, an integral long-term care system for elderly people. To accurately reproduce the kind of scenarios tackled by this model, the simulator needs to be able to represent the different behaviors that each individual within the system can have. Fine grain aspects such as the individual level of trust on the health staff or the degree of acceptation to be hospitalized can determine the interactions among the actors involved in the SSHM. For example: while some patients could be willing to be treated in a day-care center, others would prefer to stay at home as much as possible; while some of them might lie or hide information to the healthcare professionals, others would not. On the other hand, the simulator needs to provide results at different scales of population. Not only it should provide results for both the population and the healthcare system as a whole, but also results for different groups of agents and healthcare resources (e.g. hospitals, primary care centers, etc.) and even for each agent present in the scenario (e.g. patients or healthcare professionals).

Given these requirements, a System Dynamics (SD) strategy should not be used for implementing the SSHM simulator, because it can hardly fulfil any of them. A Discrete-Event Simulation (DES) strategy would not be well suited for the explicit representation of social interaction within the simulation. In the author's opinion, a Multi-Agent Simulation (MAS) strategy seems a better option, since the behavior of agents in the simulation can represent the behavior of actors in the SSHM, with the interaction between actors represented as messages between the agents. Then, it can provide each individual with different behavior in the interactions with both other individuals and the system elements. The outcomes of such simulations are not always obvious from their set-up, allowing the emergence of different phenomena as a result of different individual behaviors. Moreover, this approach can provide results at different scales, from the micro-behavior of each individual to the macro-behavior of the entire population (global phenomena that arise as a result of the aggregation of individual behaviors). Therefore, we have selected MAS as the appropriate strategy for implementing the SSHM simulator presented in this paper. We have denoted this simulator as LTCMAS, that stands for Long Term Care Multi-Agent Simulator.

Specifically, we have selected *Jason*[11] as the multi-agent platform for implementing the LTCMAS. Jason is a Java-based interpreter which allows the definition of BDI agents using an extended version of AgentSpeak(L).[49] Jason provides several infrastructures to execute a MAS following either a centralized or a distributed architecture. Whereas the built-in centralized infrastructure places all the components of the MAS in the same host, it is also possible to distribute these components in several hosts using Jade.[50] In this way, the simulator can be run on a distributed infrastructure, using parallel and/or distributed computers for providing the necessary scalability when the size of the population to be simulated reaches high orders of magnitude. For further details about how Jason uses the underlying distributed infrastructures as well as their performance, see Ref. 51.

4.2. *Simulator Implementation*

The LTCMAS includes three kinds of agents: *patients*, *professionals* of the health system, and the *case management team (CMT)*. *Patients* are the population being considered in each simulation, in this case elderly people. Each agent of type *patient* holds all the personal information describing her medical situation. *Professionals* of the health system are doctors, nurses or social workers in charge of screening patients and selecting candidates to enter the SSHM. The patient's personal and medical information will be used by these *professionals* to screen the patient and decide whether she is derived to the *case management team* or not. To do so, agents of the type *professional* apply a referral protocol based consisted on a screening test dealing with health and social aspects. As a result of the interaction between a given patient and a professional, that simulates the interview that professionals hold with patients, the patient is assigned a value for each of the metrics considered in the evaluation of the patients medical and social situations. These metrics are computed for each patient through pseudo-random values that follow the same distribution shown by the population being simulated. Values are assigned to each patient by the staff the first time they enter the system and they are updated every time the agent re-enters the system. Precisely, the interaction between the patients and the staff refers to the assignment of all these values to each patient. Patients not eligible are derived to the conventional healthcare system and, thus, they do not enter the simulated system. When they are selected, though, the *Case Management Team (CMT)* acts as the committee in charge of designing a pathway for each of them depending on his/her personal and medical information.

More concretely, the current version of the simulator includes the following information in each patient:

- Identification number within the healthcare system.
- Age.
- Gender.
- Social and health scores extracted from the referral protocol.[5]
- Flag indicating whether the patient has a caregiver or not.
- Type of caregiver (if any): relative, employee, friend, neighbor, etc.
- Caregiver availability: full, nights and weekends, part-time, etc.
- Number of medicines consumed.
- Health techniques required by the patient (e.g. number, who carries them out (i.e. health or non-health staff), periodicity, etc.).
- Agent constraints on the use of some health or social resources.

By means of the patient's identification number, the previous information is expanded with data stored in the health system databases, which were provided by the Valencian regional government and the Spanish National Statistics Institute. This data corresponds to more technical information (possibly unknown to the patient) recording, for instance, the prior utilization of the different healthcare system facilities, their efficacy, efficiency and other information. *Professionals* and the *Case Management Team* are currently considering the following aspects when assessing patients in the LTCMAS:

- Pathology and state of the illness.
- Dependency score obtained from the Barthel test.[47]
- Cognitive state score obtained from the Pfeiffer test.[52]
- Caregiver burden score obtained from the Zarit test.[48]
- Resources already being used by the patient (e.g. chronic care hospital, home help service, etc.).

Figure 1 illustrates all the agents and data sources present in the LTCMAS, as well as their interrelationships. This figure shows how the individuals in the considered population (elderly patients) interact with professionals of the health system, who, depending on certain criteria, lead each patient either to the conventional healthcare system or to the Case Management Team (CMT). In the latter case, the CMT designs a pathway for the patient (P_i), by assigning different resources among the existing ones in the social and healthcare systems. Then, the use of these resources is proposed to the patient, who might incidentally reject some of them due to personal constraints such as: willingness, economic means, etc.

The LTCMAS is designed for providing a temporal evolution of the medical state of patients as a result of the application of the pathways designed by the CMT. These changes affect the patient's data stored in the agents as well as in

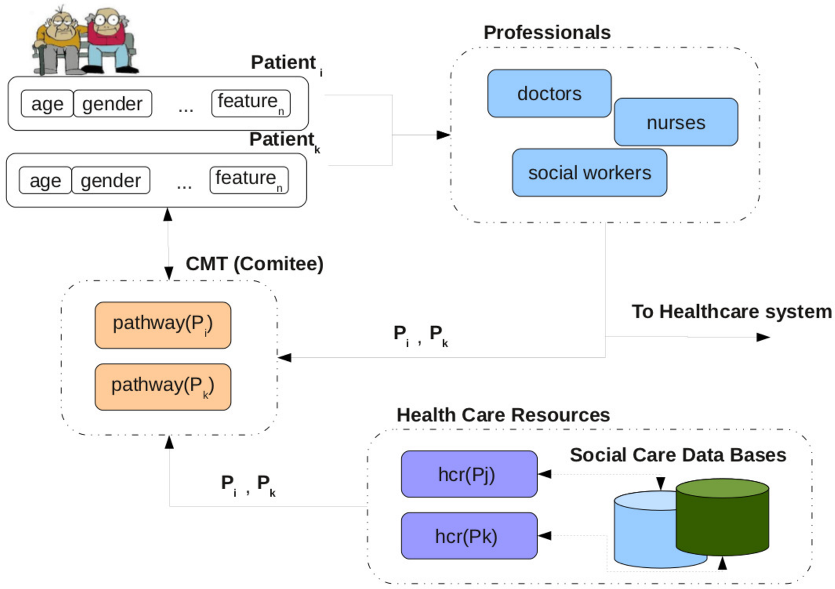

Fig. 1. Overview of LTCMAS.

the health system databases, thus closing the loop and allowing to further simulate new iterations of patients interacting with the healthcare system until their decease. Nonetheless, faithful and complete information from sanitary databases should be first obtained and analyze in order to determine the dynamics of the population being studied. Since this data have not yet been available to the authors, in this paper we exclusively present results of the open-loop working mode of the simulator, where patients execute a single iteration with the healthcare system that can take up to 9 months, as described in Ref. 5.

The time unit considered for the LTCMAS is one day, that is, this the shortest period of time that can be simulated. An iteration of a given patient consists of a complete interaction of that patient with the system. This iteration starts when the patient visits the primary healthcare center to be seen by a professional of the health system (i.e. a doctor, a nurse or a social worker). In that interaction, the professional screens the patient by means of a referral protocol consisting on a screening test containing 19 items.[5] This test is divided into two parts dealing with health and social issues, respectively. The first part contains 13 items, with a maximum score of 43 points, asking for health aspects like communication capacity, continence, mobility, emotional state or visual limitations. The second part contains 6 items, with a maximum score of 56 points, and asks for social data like home location or social support. If the screening test results in a health score greater than 10 points and, at the same time, in a social score greater than 15 points, then the patient is led to the case management team. If a lower score is obtained from the screening test, then patient is led to the conventional healthcare system and the iteration ends.

The Case Management Team (CMT) is the entity in charge designing the *pathways* that patients will follow, that is, the set of healthcare and social facilities they will use. These facilities are selected from a list of available resources the CMT can make use of. For each patient, the CMT allocates one or more resources in this list according to a set of *pathway rules* that define which resources better fit the personal and medical circumstances of the patient. That is, the CMT agent communicates with the patient agent (also extending the information exchanged with that coming from the health system databases) and, as a result of this interaction, it assigns a set of resources (the pathway) to that agent. The decision making is performed by using the rules shown in table 1 and the meta-rules listed below. The list of available resources contain both social and healthcare resources. Each resource can be assigned either as a binary resource or as a multi-level resource. Binary resources are those resources that can either be fully used by the patient (Yes) or not used at all (No). Multi-level resources are those resources that can have four possible degrees of use: Not used (No), Low Intensity (LI), Medium Intensity (MI), and High Intensity (HI). Thus, pathways take the form of resource allocations that are represented by a list of first-order logic literals (e.g. $P_i = [pcc, hhsp(li)]$, where *pcc* and *hhsp* are two examples of health and social resources as explained below). The social resources currently assigned by our system are the following ones:

- *Home Help Service, domestic housework (HHSd)*: This resource consists of a professional caregiver making domestic housework for the patient at the patient's home. It is assigned as a multi-level resource.
- *Home Help Service, personal care (HHSp)*: It consists of a professional caregiver helping the patient at home in personal tasks of different types (e.g. moving, hygiene, etc.). It is also assigned as a multi-level resource.
- *Day Center (DC)*: This resource refers to a center for the outpatient treatment of the aged and it is assigned as a multi-level resource.
- *Nursing Home (NH)*: It consists of a center designed to serve as a stable communal home for elderly people and it is assigned as a multi-level resource.
- *Remote Care (RC)*: It corresponds to the emergency service for elderly people with health risks who live alone. It is assigned as a binary resource.
- *Technical Aids (TA)*: This resource refers to the acquisition of any type of technical material (e.g. a crane) and it is treated here as a binary resource.

On the other hand, all healthcare resources are binary resources, and they are the following ones:

- *Primary Care Center (PCC)*: These are the centers where patients are first seen. Hence, there is one of these centers in each village or neighborhood.

- *Outpatient Consultants Center (OCC)*: Being assigned this resource means using a medical specialties center.
- *Day Hospital (DH)*: This resource corresponds to hospitals for certain treatments in which patients stay during the day while spending the night at home.
- *Home Hospital Unit (HHU)*: This resource refers to the situation in which some doctors and/or nurses go to the patient's home to make minor surgery and/or treatments.
- *Acute Care Hospital, outpatient service visit (ACHo)*: This resource corresponds to those hospital sections devoted to treat medical specialties such as: medical post-surgery, monitoring, or preliminary diagnosis.
- *Acute Care Hospital, short stay unit (ACHs)*: This resource consists of the patient being assigned a short stay at an acute care hospital.
- *Chronic Care Hospital (CCH)*: This resource are hospitals for patients requiring long-term healthcare.
- *Mental Health Unit (MHU)*: This resource offers health mental services for outpatients.

The pathway rules used by the CMT to design the patient's pathway can be divided into two groups, general rules and meta-rules. The general rules are applied first to design a tentative general pathway. Then, the meta-rules are used to modify this pathway and adjust it to the concrete situation of that patient (e.g. by considering the resources already being used). The general rules are based on four criteria:

Dependency degree (DD): It is obtained from the score obtained in the Barthel test.[47] A classification as independent corresponds to a score between 0 and 39 points, a degree of low dependency corresponds to a score between 40 and 85 points, and a degree of high dependency corresponds to a score between 86 and 100 points.

Cognitive problems (CP): A patient is considered to suffer from cognitive problems if the score obtained in the Pfeiffer test[52] is equal or greater than 8 points.

Clinic complexity (CC): A low CC means that the patient does not require any sanitary technique. A medium CC means that the patient requires either one or more sanitary techniques provided by non-sanitary staff, or just one sanitary technique provided by sanitary staff while his medicine consumption is lower than the average in this context (equal or less than 9 medicines.[5]) A high CC means that either the patient suffers from an illness in its terminal stage, or she requires 2 or more sanitary techniques provided by sanitary staff, or she just needs one sanitary technique provided by sanitary staff but her medicine consumption is higher than the average in this context (greater than 9 medicines).

Suitable caregiver: A patient is considered to have a suitable caregiver when he has a caregiver whose age is lower than 75 years. Additionally, if the patient suffers from a high dependency degree (DD), the caregiver should be available at any moment of the day. If the patient's DD is low, then the caregiver's availability should cover nights and weekends. Only if the patient is independent the caregiver can have a different availability (e.g. some hours on alternate days or weeks). Otherwise, the patient is not considered to have a suitable caregiver.

Taking into account these four criteria, Table 1 shows the general rules applied by the LTCMAS. Thus, for example, if the case management team receives a patient that has a suitable caregiver, with a low dependency degree, and with a medium clinic complexity, then the pathway that the CMT first assigns to that patient includes attention in her corresponding primary care center (PCC) and a low intensity degree of personal home help service (HHSp(LI)). The rest of general rules in Table 1 can be similarly understood by using the criteria and resource definitions provided above. For the sake of clarity, resources not being assigned do not appear in the table.

Table 1. General rules applied by the LTCMAS.

	Suitable Caregiver (SC)		
DD	Low CC	Medium CC	High CC
Independent	PCC	PCC	PCC
Low DD	PCC	PCC+HHSp(LI)	PCC+HHSp(MI)
High DD	PCC+HHSp(MI)	PCC+HHSp(MI)+ DC(LI)	PCC+HHSp(MI)+ DC(MI)
	Not Suitable Caregiver (SC)		
DD	Low CC	Medium CC	High CC
Independent	PCC+RC	PCC+RC	PCC+RC
Low DD	PCC+RC+HHSd(LI)	PCC+HHSd(MI)+DC(LI)	PCC+HHSd(LI)+ HHSp(LI)+DC(MI)
High DD or CP	PCC+NH(LI)	PCC+NH(MI)	PCC+NH(HI)

After a first tentative pathway has been assigned by using the previous general rules, it is adjusted by sequentially applying the following set of meta-rules:

(1) If the patient has important cognitive problems (i.e. a score of 8 points or more in the Pfeiffer test) and he has a caregiver, then, the HHSp resource is added to the pathway or its intensity is increased by one degree if it was already present. When the HHSp resource is already at its maximum degree (HI), the DC resource is in turn added or increased.

(2) If the patient does not have important cognitive problems but she has a caregiver with an intense burden (i.e. a score of 56 points or more in the Zarit test[48]) then, both the HHSp and HHSd resources are added to the pathway, or their intensities are increased by one degree if they were already present. If either the

HHSp or HHSd resources are already at their maximum degree (HI), then the DC resource is in turn added or increased.

(3) If the patient is already using the DH resource, then this resource is kept in the patient's pathway.
(4) If the patient is already using the ACHs resource and his/her clinic complexity is high, then this resource is kept in the patient's pathway. In the case of a low or medium clinic complexity, he is only assigned the CCH resource. In any case, the rest of resources are removed from the pathway.
(5) If the patient is already using the CCH resource, he/she will exclusively continue using this resource in his/her pathway, and the rest of resources are removed from the pathway.
(6) If the patient was previously using ACHo and both the DD and the CC patient's criteria are high, then the ACHo resource is replaced by the OCC resource. If any of this two criteria is not scored as high, then the patient remains using the ACHo resource, which is added to the pathway.
(7) If the patient was previously using OCC, then the OCC resource is replaced by the PCC resource in the pathway, provided that the patient's clinic complexity is low. Otherwise, the OCC resource is also added to the pathway.
(8) If the patient is already using HHU, then this resource is added to the pathway, whereas the PCC resource, if present, is removed.
(9) If the patient fulfils the next three conditions: first, he/she has a high DD; second, he/she is assigned to either the HHU resource or to the HHSp resource with a high intensity degree; and third, he/she has not been assigned to any of NH, DC, CCH or ACHs resources. Then (if the three conditions are fulfiled), the TA resource is added to the pathway.
(10) If the patient was previously using MHU, his/her dependency is not high and he/she has not been assigned to any of NH, CCH or ACHs resources, then, the MHU resource is added to the pathway.

Finally, once the pathway has been fully designed then it is proposed to the patient. At this stage, he can reject those resources that do not fit his/her personal constraints. For instance, a patient might refuse using the day center due to economic issues. Thus, the set of resources actually used by a patient are the remaining resources in the pathway, after having discarded those that are marked as rejectable.

5. Validation and Performance Evaluation

5.1. *Validation*

The LTCMAS has been validated by using real data from a pilot that took place in the Valencian region (Spain),[5] where the Sustainable Socio-Health Model (SSHM) was applied to a group of patients, and its effects over the use of healthcare and social resources were analyzed. Thus, we have executed the simulator using an exact copy of the population described in this pilot as the input data. Although all the results are also available in that reference work, in order to make this paper self-contained we have reproduced part of those results in this paper.

Table 2 shows the validation results of the LTCMAS. The column labeled *Data* reproduces the same results shown in Table 3 of the reference paper[5] under the label "Pre-intervention group (n=101)". These results describe the resource consumption required by the group of selected patients before they entered the SSHM. This group was formed by 101 patients. In turn, the values shown in the column labeled *SSHM* correspond to those shown in Table 3 of Ref. 5 under the label "Post-intervention group (n=101)", which describe the resource consumption assigned by the SSHM when applied to the intervened group of 101 patients. We have fed the simulator with 101 agents with the exact characteristics of the individuals within this group (loaded from a database coming from the pilot), and the results provided by the LTCMAS are shown in the column labeled with the same name.

Each row in Table 2 shows the number of patients using each of the resources considered in the SSHM, which are grouped in healthcare and social resources. Values for multi-level resources (i.e. HHS, DC and NH) indicate the number of agents using the resource in any degree: Low Intensity (LI), Medium Intensity (MI), or High Intensity (HI). The usage of the Home Help Service (HHS) resource is actually an average of the more specific services dealing with domestic housework (HHSd) and personal care (HHSp) that are obtained from the simulation, so this value can be compared with that coming from the reference work. In order to exactly consider the same model outcomes, Table 2 also includes the usage of the Primary Care Center (PCC) resource, although the values for this resource were only cited within the text of the reference paper.

Table 2. Validation results of the LTCMAS.

Resources	Data	SSHM	LTCMAS
Social			
Home Help Service (HHS)	29	32	32
Day Centre (DC)	3	22	20
Nursing Home (NH)	0	9	10
Remote Care (RC)	16	25	25
Technical Aids (TA)	3	4	5
Healthcare			
Primary Care Center (PCC)	101	95	94
Outpatient Consultants Centre (OCC)	14	8	8
Day Hospital (DH)	1	2	2
Home Hospitalization Unit (HHU)	2	2	2
Acute Care Hospital, outpatient service visits(ACHo)	30	25	26
Acute Care Hospital, short stay unit (ACHs)	6	1	1
Chronic and long-term care hospital (CCH)	1	3	5
Mental Health Unit (MHU)	3	2	2

Table 2 shows that not only the global system behavior predicted by the LTC-MAS exactly matches that obtained from the real experiment (in the sense that the use of each resource increases or decreases as so did in the pilot), but also the number of patients being assigned to each resource by the simulator is very similar to that obtained in reality. In the case of the social resources, two of them (HHS and RC) exactly match, while the other three (NH, DC and TA) differ in one or two patients. In a population of 101 individuals, this means a percentage of difference lower than 2%. Regarding the healthcare resources, the simulator provides the same exact result for 5 resources (MHU, OCC, DH, HHU and ACHS), while differing in 1 patient in two other resources (PCC and ACHO) and in two patients in the remaining resource (CCH). Again, the percentage of error is less than 2%. Thus, these results fully validate LTCMAS as a faithful ICT tool for simulating the behavior of the SSHM.

Although the validation of the simulation tool is application dependant (in this case we have validated the proposed tool for simulating the SSHM with certain rules and meta-rules, and with given population data), the tool can be easily modified to simulate different policies, by simply changing the rules and the meta-rules applied to define the pathways. Additionally, the underlying concept of simulating the decision making process of social and health staff about patients through rules and/or meta-rules can be used to simulate any other social and/or health system. In this way, the proposed framework can be reused for simulating other social and health systems.

5.2. *Performance evaluation*

In order to asses the scalability and feasibility of the developed simulator, the computational workload that this tool represents for a computer platform should be evaluated. For this purpose, we have measured both the percentage of CPU utilization and the execution times required for running different simulations with increasing population sizes. The results shown in this section refer to the use of the centralized infrastructure (i.e. all the components of the LTCMAS are located in the same host), in order to study the maximum population size that a single standard current computer can support and the execution time required for that population size. Concretely, we used a computer platform consisting of an Intel(R) Core(TM) i7-2620M processor with 8 GBytes of DDR3 (1,333 MHz) RAM, executing Linux 3.1.10-1.16-desktop x86_64 operating system (OpenSuse 12.1 distribution).

The percentage of CPU utilization was very close to 100% in each of the simulations executed, proving that the multi-agent simulation executed over the centralized infrastructure of the Jason platform managed to properly use the CPU resources of the computer platform. Regarding the execution times, Table 3 shows, in the central column, the amount of seconds required to run different simulations with increasing population sizes. The time values in this table were computed as the average value of the execution time required by ten simulations of the same population size. The mostright column shows the required execution time per agent, computed as the total execution time (the value in the central column) divided by the population size (mostleft column).

Table 3. Execution times required by LTCMAS for different population sizes.

Number of agents	Time (sec.)	Time (sec.) per agent
101	1.13	0.0112
1000	3.62	0.0036
10000	12.93	0.0013
50000	361.76	0.0072

Table 3 shows that LTCMAS can simulate a population of up to ten thousand agents in a few seconds, and a population of fifty thousand agents in around five minutes. However, it must be noticed that the target population of the SSHM is a small fraction of the population. Thus, for example, at the time of the experimental study[5] the target population (the population that could fit the SSHM criteria) in the Valencian region was estimated in 65,000 patients, for a total population of around 2,500,000 people, that is, around 2.6% of the total population. Taking into account this percentage, these results show that LTCMAS can simulate long-term care systems for large populations within a few minutes by simply using a standard computer.

In order to estimate the performance that can be expected when executing LTCMAS on a standard computer platform, we have made a curve fitting from the values shown in the center column of table 3. Taking into account these values, the resulting asymptotic cost would be quadratic ($O(n^2)$, where n is the number of simulated agents). The asymptotic curve would be given by the polynomial

$$1.531 \times 10^{-7}x^2 \; - \; 0.0004x \; + \; 2.478 \tag{1}$$

For illustration purposes, figure 2 shows the comparison of the asymptotic curve and the values shown in table 3. Although the simulation of long-term care systems is an off-line task without timing constraints, this curve may be used as an estimation of the required execution time for different population sizes.

In case this curve does not fit the existing timing constraints (if any) for a given population size, there are still another ways for improving the simulator performance, like the optimization of the current simulator setting or the use of the distributed intrastructure (e.g. Jade[50]). Regarding the former one, the LTCMAS is currently loading all the patient data in memory prior to the execution. A simple optimization could consist of directly querying the patients and health system databases. Regarding the latter one, the use of a distributed infrastructure of the multi-agent platform would allow the simulator to properly scale up with population sizes and/or healthcare systems of different orders of magnitude. In that case, each computer platform could simulate a different region of the healthcare system, with its own screeners and CMTs working in parallel.

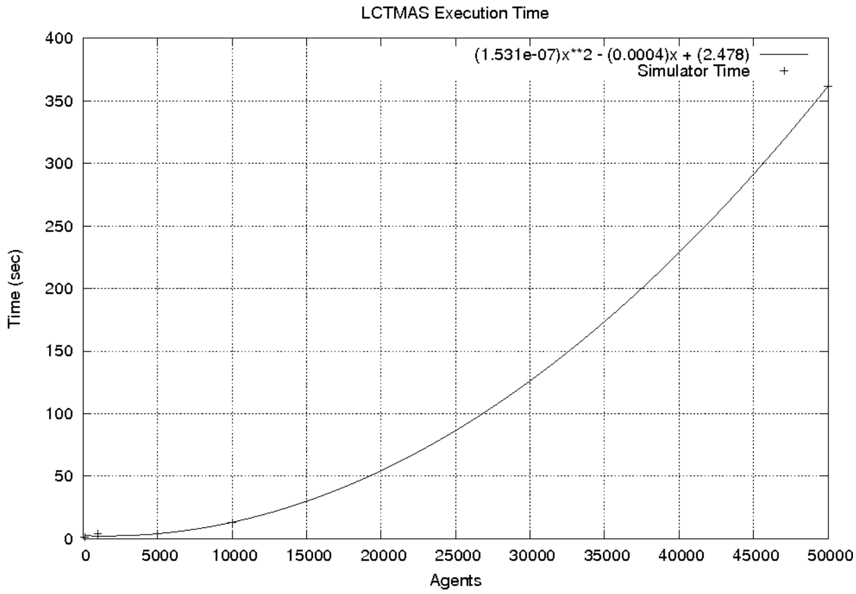

Fig. 2. Simulation time of LTCMAS on a standard computer platform and its polynomial curve fitting.

6. Conclusions and Future Work

This paper has presented a computer-based simulator of integrated long-term care systems for elderly people. This tool simulates one of the holistic models developed for people that need long term care, and it consists of a multi-agent based system developed on the *Jason* platform, the well-known Java-based interpreter for an extended version of the AgentSpeak(L) programming language. The implementation of the simulator through multi-agent systems allows the tool to include the human interactions, preferences and social abilities that take place between elderly people and the staff of healthcare systems (doctors, social workers, psychologists, nurses, etc). On other hand, the use of a multi-agent platform like Jason, that includes a distributed infrastructure capable of taking advantage of distributed computer architectures, allows the tool to easily become scalable, in order to simulate different orders of magnitude in the population size.

The validation results show that the tool can provide faithful insights in the effects of long-term care policies, regardless of the kind of computer platform available. Also, the performance evaluation results show that the tool can simulate long-term care systems within an execution time that follows a quadratic asymptotic behavior with the population size when using a single standard computer platform and the centralized Jason infrastructure. Since the simulation of healthcare system is usually an off-line task without timing constraints, the cuadratic behavior seems appropriate. Nevertheless, for those cases requiring much larger populations (and therefore longer execution times), the Jade distributed infrastructure could provide the required parallelism to reduce the execution time.

As a future work to be done, we plan to add sanitary databases to LTCMAS, in order to allow each agent to perform different iterations within the system. This closed-loop working mode will allow LTCMAS to simulate not only large population sizes, but also their evolution of along large time periods.

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