Towards an Agent-based Model to Monitor Epidemics and Chronic Diseases in DR Congo

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Abstract: Many contagious diseases occurred around sub-Saharan countries in the last decade due to the inefficiency of health structures to anticipate disease outbreaks. In a huge poorly-infrastructured country such as The Democratic Republic of Congo (DRC) with insufficient health staff and laboratory facilities, to provide quick response to an urgent case of epidemic is challenging especially facing the development of its rural areas. As DRC's Health System has three levels (peripheral, regional and national levels), from producing health data at peripheral to national level that takes the decision, it can take time resulting in the spread of disease. The lack of communication between health centers and laboratory facilities in the same health zone does not contribute to regional riposte. This paper proposes to face this problem using an agent-centered approach to study through simulation how to improve the process. An experiment is described by agentifying two health zones on the same regional level to show how it can reduce the decision time.. It consists of 2 peripheral coordination offices, 2 labs and 2 health zones the former with 12 health centers and the latter with 20 health zones. The interaction between these agents will provide a first model to be compared with the current system in other to reduce decision time.

1 INTRODUCTION

Access to health care is a major concern in developing countries. The Democratic Republic of Congo ranks among the poorest countries according to its HDI[1] (UNDP, 2016). Despite its millions of hectares of arable land, this vast country of Central Africa is experiencing serious difficulties in improving the living conditions of its population, particularly in the field of basic health care. Life expectancy at birth is 50 and 53 respectively for men and women (WHO, 2014).

The country is currently divided into the city-province of Kinshasa and 25 other provinces. The provinces are subdivided into territories which are divided into sectors. To facilitate the supervision of health structures, the DRC health system is divided into three levels (Ministère de la Santé Publique de la République Démocratique du Congo, 2006): central, intermediate and peripheral. The nearest level to the population is the peripheral area composed of 518 health zones (HZ) that coordinate the actions of the health facilities. A HZ is divided into Health Area (HA). One or more Health Centers (HC) can be found at an HA. A General Referral Hospital (GRH) ensures the complementary packages of health activities of the HZ. The Central (national) level defines the policies, strategies and resources of the sector. It enforces strategies and policies at the peripheral level through the intermediate level called the Provincial Health Division (PHD), which coordinates primary health care and technical support activities for health zones in a province.

Each HZ has a Health Information Bureau (HIB) which retrieves the aggregated data from all its supervised HA to national level for decision measures. The HIB organizes weekly meetings with the Health Zone Executive Team (HZET) to decide on suspicious cases to report to the hierarchy. HZET manages health facilities (HF), that includes HC and GRH, and Community-based organizations (CO).

Figure 1 represents three levels of DRC Health System in with each HZET supervises many HC and one GRH at peripheral level. PHD at intermediate level provides technical assistance to HZET while

[1] Human Development Index

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Direction of Disease Control (DDC) under National Health Minister (NHM) gives national policies to 26 PHD at central level. Provincial Health Minister plays the role of political authority.

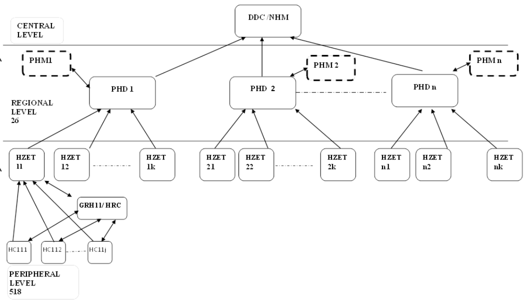

Figure 1: Three levels of DRC health system.

As a WHO member country, DRC benefits from the technical and financial support of the partners to respond to epidemics under the conditions stipulated in the International Health Regulations (IHR) (WHO, 2005). All cases of these four diseases must be automatically notified to WHO: smallpox, poliomyelitis due to wild-type poliovirus, severe acute respiratory syndrome (SARS) and cases of human influenza caused by a new subtype. On the ever-changing list of diseases provided by IHR, each country is free to add other diseases with epidemic potential or not, which constitute a public health problem.

Access to basic care is difficult for a large part of the population. People visit the health facilities in case of extreme urgency. This is more evident in rural areas where the diminishing resources of farmers do not allow them to consult medical services often. Often health care is provided during free medical workers' campaigns.

To collect data about suspicious cases to the hierarchy for decision-making, the most widely used ways are described as follows (Ministère de la santé, 2012):

-Health facilities;
-Information from community members who are experienced in unusual symptoms and signs;
-Pharmacies that report increasingly purchases of the same drugs or detect recurrent treatment;
-School reporting an unusual rate of pupil absences due to bizarre signs and symptoms;
- New suspect cases discovered during medical consultations;
-Medical records providing information on new diseases detected in the population;
-Media (radio, television or newspapers) reporting unusual events;
-Civil registries indicating an increasing rate of maternal deaths;

Despite great efforts to improve disease surveillance and response, DRC faces big challenges in identifying, diagnosing and reporting infectious diseases properly due to the remoteness of communities, the inadequate transport and communication infrastructures and the lack of qualified health staff and laboratory facilities to ensure accurate diagnosis.

The challenge, in this paper, is to find new technical solutions based on real population life and situation to improve health services organization and data sharing in order to detect infectious disease very quickly, organize the response and prevent the spread of the disease.

2 ISSUES

In this paper, we present a part of this challenge. We propose a multi-agent system to simulate the interactions between actors working together to organize an optimal response to epidemic detection. When a new case of infectious disease is suspected in HC, actors will collaborate to report it to PHD through HZET. The approach will be based on the current DRC heath system processes to extract relevant actors' tasks. The identification of these actors and their tasks will provide the opportunity to simulate a new system that distributes the entire competences of the old heath system to those actors in order to improve their collaboration and eventually shorten the making-decision time response. Work-sharing protocols will be proposed to simplify the complexity of the data sources.

A MultiAgent System (MAS) is a set of agents situated in a common environment, which interact and try to reach a set of goals. Through these interactions, a global behavior, more intelligent than the sum of the local intelligence of multiagent system components, can emerge. By 'agent' we mean a software entity evolving in an environment that it can perceive and within which it reacts. It is provided with autonomous behaviors and some objectives. Autonomy is the main concept in the agent issue: it is the ability of agents to control their actions and their internal states. The agents' autonomy implies no centralized control (Wooldridge, 1999). One of the advantages of MAS is to model systems where a global description is not possible at any given moment. Multiagent conception is well suitable to model actors described in Figure 1.

This paper focuses precisely on improving the process of reporting health data from the peripheral level to the hierarchy for rapid decision-making and anticipate as much as possible the medical response.. Hierarchical dependency between levels forbids periphery to directly transmit health data to National level for quick decision. As information must pass through intermediate level (PHD) combined with often defective means of communications, it drastically hampers the fight against a propagation of a disease.

The next section shows the related work in healthcare and multiagent domains. Section 3 describes the healthcare system and problematic in DRC. The methodological approach and agent's models are explained in section 4. The model is validated by a simulation presented in section 5. Future research directions and conclusion are developed in section 6.

3 RELATED WORK

Information and Communication Technology is a powerful solution for health care in developing countries (Greenberg, 2005). It made possible the improvement of remote patient follow-up (Wouters and all, 2009), controlling the progression of malaria (Zurovac and all, 2012), improving the uptake of information from health systems (Mutale and All, 2013).

Mobile phone coverage in Africa grew from 10 percent in 1999, 65 percent in 2008 to more than 70 percent in 2012(Aker and Mbiti, 2010). This technology is used to cover numeric fraction. To improve drug adherence and suppression of plasma HIV-1 RNA load in Kenyan, mobile phone communication between health-care workers and patients starting antiretroviral therapy was set up (Lester and all, 2010).Text-message reminders sent to health workers' mobile phones improved and maintained their adherence to treatment guidelines for outpatient pediatric malaria (Zurovac and all, 2011).

Phone traces are powerful tools to estimate population migration while investigating an outbreak. These techniques were used to demonstrate the feasibility of rapid estimates and to identify areas at potentially increased risk of outbreaks in Haiti (Bengtsson, 2011). They produced reports on SIM card movements from a cholera outbreak area at its immediate onset and within 12 hours of receiving data. Results suggest that estimates of population movements during disasters and outbreaks can be delivered rapidly and with potentially high validity in areas with high mobile phone.

A trial of mobile phone text messaging for diabetes management in an eight-month period to transmit data such as blood glucose levels and body weight to a server that automatically answered with a monthly calculated glycosylated hemoglobin result. The trial results suggest that sms may provide a simple, fast and efficient adjunct to the management of diabetes (Ferrer-Roca, 2004).

In developed countries SMS messages have been widely used to remind patients of scheduled appointments (Hasvold, 2011; Car and all, 2008). Similarly, more complex mobile phone applications have shown significant improvement in the follow-up of malaria patients in Thailand (Meankaew, 2010). The same approaches have been tested in Africa as part of the SMS reminder package to improve patients' adherence to antimalarial treatment schedules in .six sub Saharan countries (Zurovac, 2012).

Even if text messaging is the simplest and the most widely used technology function for which all of the reviewed studies have shown ease of use in reporting periodic data from the health system periphery to control managers, it however remains to be proved for interventions targeting individual patients, for whom a high facility workload or illiteracy may present a barrier (Zurovac, 2012).

Simulation has a broad application potential in healthcare. The more general classification is clinical, operational, managerial and educational simulation (Barjis, 2011). Managerial and operational of simulation are closely interrelated. These two together are the core components for healthcare process management. Some challenges and trends of simulation models in healthcare in the past two decades have been developed (Almagooshi, 2015). The design of a web-based clinical decision support system that guides patients with Low Back Pain in making suitable choices on self-referral has been experienced in Netherlands (Nijeweme-d'Hollosy and all, 2016).

MAS is used to describe an approach to the analysis and development of telemedicine systems (Mea, 2001), to manage communications in wireless sensor networks (Jamont and Occello, 2007), the epidemiological decision support system (Weber and all, 2006), the care of seniors at home (Mercier and all, 2013), decision-making for the monitoring and prevention of epidemics (Younsi, 2016), evaluation of the disaster response system (Bae, 2017), medical sensor modules in conjunction with wireless communication technology supporting a wide range of services including mobile telemedicine, patient monitoring, emergency management and information sharing between patients and doctors or among the healthcare workers (Byung-Mo and All, 2006) .

MAS can be considered a suitable technology for the realization of applications for providing healthcare and social services where the use of loosely coupled and heterogeneous components, the dynamic and distributed management of data and the remote collaboration among users are often the most requirements (Bergenti, Poggi, Tomaiuolo, 2013). Cooperation in the Agent Technology can provide better healthcare than the traditional medical system (Jemal and All, 2015). Real programs built on the multiagent paradigm are still evolving towards a complete maturity, and the variety and complexity of the e-health scenario make it one of most interesting application fields, able of verifying the advantages of their use of the conditioning their evolution (Bergenti, Poggi, Tomaiuolo, 2016).

MAS was used to monitor a generic medical contact center for chronic disease environment, detect important cases, and inform the healthcare and administrative personnel via alert messages, recommendations, and reports, prompting them to action (Koutkias, Chouvarda and Maglaveras, 2005). Developed MAS applications in healthcare can provide a reasonable way to mitigate the cost due to increased demand for services (Shakshuki and all, 2015).

An Agent-Based Model (ABM) with Geospatial and Medical Details was used to evaluate the efficiency of disaster responders to rescue victims in a mass casualty incident situation in South Korea (Bae, 2017).

ABM can cooperate to share tasks between sensors to observe a phenomena (Jamont, 2009), to manage diabetes treatment between Caregivers and Patients. The usability evaluation of a collaborative information system for dementia assessment built using a user-centred design approach was experienced in Norway (Berglind and all, 2016). But from several research papers we have reviewed we didn’t find a paper addressing ABM in the sharing of tasks of the actors involved in the processes of the feedback of the multi-source health information and the organization of the response to a disease with high epidemic potential.

4 HEALTH DISTRICT IN DRC

4.1 Administrative Structures

The management of the patient and the reporting of suspected cases are managed by the peripheral level through health centers and the general reference hospitals. The health data collected by the HF are transmitted to the HZET for consolidation and transmission of aggregated data from the HZ to the PHD. This intermediate level structure convenes weekly meetings to analyze data from each HZ, decides on actions to be taken and produces consolidated data from across the province.

The PHD must transmit the health data from its province to the central level for a second analysis and national consolidation. If suspected cases reported by HZ require deeper investigation, laboratory tests or kits, the PHD will seek technical and financial support from the central level in the event of its inability to provide the necessary means.

The Disease Control Direction (DCD) is the central respondent. It also organizes weekly meetings to analyze health data from all provinces. It often provides advice and recommendations to PHD for monitoring suspect cases in accordance with the national policy of the sector. It can solicit government authorities, special programs, partners and even the international community. Figure 1 shows the data from the periphery to the national level. Since decision-making is pushed back to the central level, it can intervene belatedly at the risk of witnessing an alarming spread of an epidemic with high epidemic potential.

4.2 Structure Dependencies

The first difficulty in managing epidemics begins with the processing of data from multiple sources at the HZ level. National policy has expanded the list of groups of individuals who can retrieve information from suspect cases (Figure 2). This information, which often comes in the form of phone calls or narrative, is not exhaustive. Hence the interest in diversifying the mode of communication by adding text and voice sms, tweets and phone calls on green lines.

A second difficulty in the accurate identification of suspect cases is the insufficient number of qualified health personnel (Ministère du Plan et de Suivi de la Révolution de la République Démocratique du Congo, 2014). In spite of the training courses organized by the HZET for the benefit of community relays and staff of health facilities, there are gaps in the implementation of the information brought to their attention. For example, the PHD conducts a thorough investigation by qualified personnel as soon as the number of suspected cases reaches the threshold for each pathology. Lack of information on the list of the nearest laboratories delays response time to confirm cases and ensure accuracy of diagnosis.

Hierarchical dependence does not favor communication between structures of the same level. This is the case for the health areas of a HZ, contiguous health areas but belonging to different PHD. This lack of dialogue can lead to the non-detection of an epidemic for the simple reason that the number of cases is not reached in a HZ. However, by combining this number with that of the contiguous health areas, we could detect the pathology at the intersection of the provinces, which constitutes a business lock.

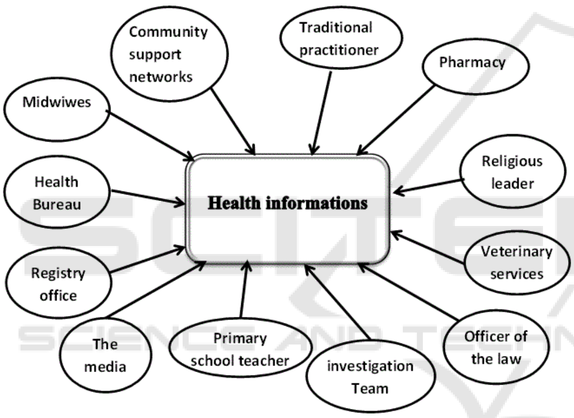

Figure 2: Many structures are designated to produce Health data at each Health Zone.

4.3 Collection and Response for Epidemic Surveillance

The designated structures report information relating to suspect cases to the FOSA or HZET. Apart from the pathologies of the International Sanitary Regulations (smallpox, poliomyelitis due to wild polio virus, human influenza and Severe Acute Respiratory Syndrome (SARS)), the authorities have added to the list of diseases with epidemic Eradication measures or Elimination and other chronic diseases. Reporting of cases is immediate, weekly, monthly or quarterly according to the contagiousness of the pathologies.

4.4 Data Collection and Epidemics Response

As soon as they appear, suspect-cases information must be transmitted to HZET by all data providers indicated on 3.2. . When the number of suspect cases in HZ equals to the threshold according to the pathology observed, a rapid riposte team (RRT) has to investigate some HC and the population of the concerned HZ to make sure the allegation was correct. The investigation of RRT team could result to laboratory tests of some samples. In case of riposte many hierarchical structures such as PHD and national level would intervene to provide technical and financial support.

The process used to organize riposte (Ministère de la Santé Publique de la RDC, 2012) is shortly described in Figure 3. HZET analyze the report of surveillance to determine if the number of suspect case has reached the threshold to order an investigation. RRT will research new cases at HA according to the clinical definition of case. It will find out new determinants of the outbreak to report to PHD in other to realize the response.

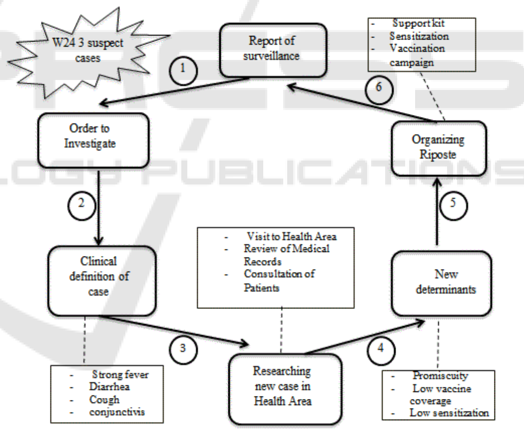

Figure 3: Cycle of outbreak response.

A final evaluation of outbreak response presented as a report of the process can be shared with other HZ and Health Facilities.

This type of system is well suited to MAS using an AEIO representation. The real system is analyzed with four elements the **A**gent, the **E**nvironment, the **O**rganizations and the **I**nteractions between the agents. This model will be detailed in the next part.

5 INDIVIDU-CENTERED MODELS

“The process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies (within the limits imposed by a criterion or a set of criteria) for the operation of the system” is a definition given by (Shannon, 1977) for simulation activity.

At this stage of this research, the simulation's objective is to understand the DRC healthcare system for Epidemic diseases. Multiagent-based-simulation (MABS) allows explicitly modeling the behavior of each individual and viewing the emergent system from the interactions between the individuals.

In further work, on the one hand, we will determine some metrics to analyze process simulations and on the other hand, we plan to develop modules in embedded systems (like phones or tablets) to assist the end-user in the data collection, coupled with the multiagent system.

(Morvan, 2013) proposes a survey on MABS and presents several multiagents platforms. In these existing platforms, we have not found solutions which can act as both a simulation system and a tool to end-users on embedded systems.

However, the DIAMOND method and the MASH simulator developed in LCIS Laboratory will be used to model and simulate the system (Jamont and Occello, 2007, 2009).

The hierarchical organization for collecting data in DRC (healthcare system) administration is a good candidate for a multiagent model because there are several kinds of agent with their own goals which share the same global achievement. In the process described previously (figure 3), the agents use some knowledge and tasks to perform a main goal together: collecting data in order to respond with efficiency to epidemic. The process is modeled by agents able to be simulated in the MASH simulation platform. The advantage of doing this is to have an individual-centered vision of the process. After that, we will be able to contribute to the improvement of the process with an exterior view provided by the simulation and propose changes and ideas to improve the response time, for example.

This section shows the steps to break down multiagent system’s elements.

5.1 Agents’ Tasks and Knowledge: The Internal Behavior

For starting the analyses, each individual agent’s behavior is studied. It is a way of seeing things at a micro level, the phenomenon (at macro level) does not change and the process remains the same but the observer’s level changes.

The goal is to be able to adjust the behavior of each individual agent and possibly add skills to certain nodes or node types.

The first step is to model into agent the elements of the process. For the problem, it is the health centers, the main hospital of the health areas, province districts and national health entity related to the administrative structures and HZET and RRT for human team working group. The figure 4 shows the internal behavior of the RRT.

For each agent, we have to list all their skills, what information will be required to store and to handle and how the agent acquires this information. This information should be acquired directly by perception (e.g. the user grasps something) or on demand by asking other nodes (higher hierarchy or same level nodes).

With this step, we obtain for each agent, a vision of the relevant knowledge to perform its individual tasks. This is all the necessary information for the agent who works in the system. The result is a set of tasks that the agent can perform. These tasks correspond to the skills of each node. Some skills are made locally without need to contact other agents. But to achieve a goal, an agent should have partial information and needs to ask other agents to complete their goal. However, we will have cooperative behavior in opposition to completely individual behavior entirely internal to the agent. This kind of social behavior reflecting an interaction among several agents: either to gain information or to share tasks.

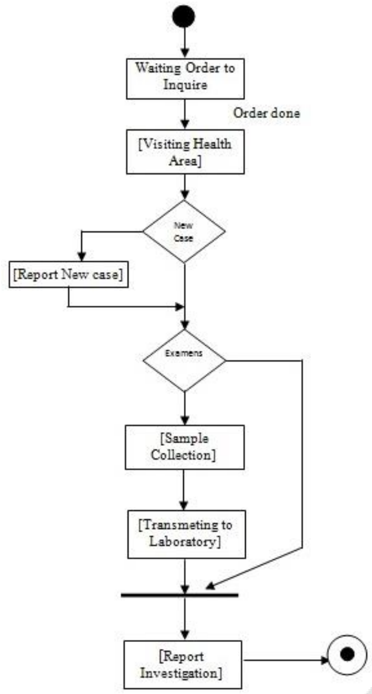

Figure 4: Investigating an outbreak.

5.2 Agent's Sharing Data and Interactions

5.2.1 Social Behavior

In this step, we will have to create interactions between nodes for example to back up information (HCR to HZET) or to receive orders (HZET from PHD). These interactions should be between different partner groups such as health areas. In the implementation, we define very simple interaction protocols for data exchange such as receiving information, answers/queries or order to perform a task. For some tasks, such as health alert surrounding areas, it is no longer just a request for information but cooperative behavior; that is to say behavior that brings into play several kinds of agents. In need thereof soliciting other agents, the agent is led to use interaction protocols. We will therefore define how this behavior will be realized by defining a more sophisticated interaction protocol than query/response. Diverse protocols are available for negotiating, giving orders, waiting for answers. The interaction patterns that will govern this cooperative behavior will be organized between the agents.

5.2.2 Interaction Protocols

The protocol is a part of the agents' knowledge. Agents have a list of protocols that they should initiate or that they are able to use to answer others. For the moment, we use a simple protocol with two states as represented in figure 6. For example, Agent A1 launches an instance of protocol P1, it is in the state S1. The agent A2 receives a solicitation of A1 with the performative "information" in the state S1. A2 knows the protocol and searches the next transition; it passes in state S2 and sends an acknowledgment to agent A1. A1 treats the message and the conversation finishes. The ACL FIPA compliant Performatives are used:

- *RDCMessage.ACL_QUERY_REF* for queries/answers,
- *RDCMessage.ACL_REQUEST* for an order to perform a task and,
- *RDCMessage.ACL_INFORM* for inform/acknowledgment.

5.2.3 Position in the Organization

The last step is to take into account the position in the organization when an agent will initiate interactions with each other. An organization should be a hierarchy or a simple group. As an example, to alert neighboring HZ, health center agents will know the surrounding areas of health, which is a group, that is to say an organization in the multiagent system and make a decision based on its position in this group. The agent's position in the organization is integrated in the decision making loop.

5.2.4 Agent's Internal Decision Making Loop

The previous steps give the agent's skills, the agent's complex behavior (internal and social), the knowledge of interaction protocols. We will now build the agent decision loop. On the one hand purely individual behavior runs only with an agent's context information and does not need other agents to complete the agent goal. On the other hand, social behavior involves relationships with other agents. Using an individual-centered approach defines the agent at micro level so the interactions with other agents have to be merged with the internal behavior in the agent's decision loop. The individual and cooperative behaviors are both integrated into the decision making loop. In the individual behavior, there is a set of tasks that are launched in the internal decision loop. In its decision loop, the agent should have to respond to the message from others' which are part of interaction protocols initiated by other agents or parts of own launch of the agent interaction patterns. These tasks have to be synchronized with the messages received from the others agents.

As an external view, basically, huge decision loops, which are decentralized in the several kinds of agents, seem to be synchronized at the system level, but in fact, each agent decides what state it passes according to its knowledge and the state of its interactions.

5.3 Collaborative Tasks of Agents

Agents would collaborate to achieve some objectives. To investigate on HA, RRT must wait for an order from HZET. The later receives health data every week from HC and checks if the threshold of the followed pathology has been reached. The same collaboration is needed between RRT and HA, RRT and Laboratory. The sequence diagram (Figure 5) gives a snapshot of the kind of collaboration found in agents concerned with an outbreak investigation.

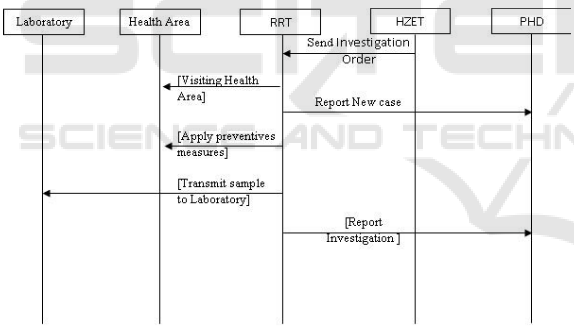

Figure 5: Sequence diagrams of investigating an outbreak.

5.3.1 Message Format for Interaction

The messages exchanged between agents contains sender and receiver agents, protocol information and data to manage like *[sender; receiver; conversation; perform; protocol; inst_prot; state_prot; data]*. The data follow a format according to the performative.

To interact through a message sent by another agent, a simple protocol is established. For instance when RRT asks a laboratory to perform exams, he has to first check its state to be convinced that it can answer his request. A simple protocol with acknowledgment is used.

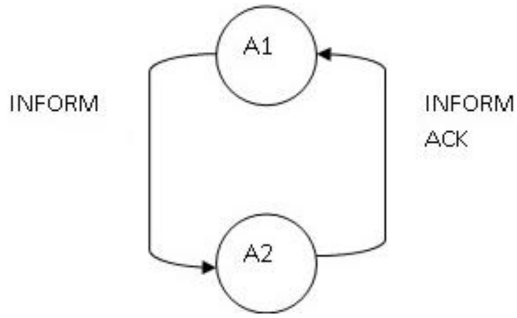

Figure 6: Protocol for information with acknowledgment.

The agent changing state when he asks for information and when he receives the answer to his request is represented in Figure 6. In a future simulation, a negotiation protocol with a call for proposal to several laboratories will be tested. However, the agent launching the conversation should negotiate among laboratories which one is available, near or powerful.

6 SIMULATION RESULTS

In order to test and evaluate our approach, we adapted MASH simulator developed for a wireless sensor multiagent system (Jamont and Occello, 2009). We focus our simulation to the former Equateur Province that was split in 2015 into the new, smaller Equateur province, as well as the Tshuapa, Mongala, Nord-Ubangi and Sud-Ubangi provinces.

Located in the north of the country, the province bordered the Republic of the Congo to the west, the Central African Republic to the north, to the east the Orientale province, and to the south the Kasai-Oriental, Kasai-Occidental.

The former Equateur registered 18% of cholera outbreak suspect cases on 2016 with 31% of death (Ministère de la Santé Publique de la RDC, 2017). The crossing of many rivers facilitates the spread of a disease such as cholera if health staffs don't alert the population as soon as a suspect case is noticed.

The simulation concerns precisely Tshuapa Province that doesn't register cholera outbreak suspect case on 2016 while its neighbors Equateur and Mongala provinces have respectively 2751 and 1781 suspect cases with deaths. The main idea is to see how the future system would react if each actor of health system could perform his own task with autonomy. These experiences could result to many scenarios and the best of them will be proposed to DRC's Health System to reduce time decision as each actor can execute his talks according to the knowledge of environment and outbreak he will be provided with.

We chose two HZ of Tshuapa PHD for the simulation. Befale and Boende are HZ that didn't register cholera outbreak in 2016 but they are bordered with two provinces crossed by rivers that encountered many deaths due to Cholera at the same period.

To respond to an outbreak noticed at a HC, health staff of the concerning HC must refer to HZET. In their turn HZET must refer to PHD and PHD to central level. This chain of hierarchical contacts can enlarge time decision.

In our simulation we worked with this hypothesis: each actor must contact immediately the nearest one able to answer to his request or to use his information to make decision. We considered only three HA of each HZ and twenty HC in blue with two HZET (in yellow for each HS) and two medical test laboratories (Labo in green square).The suspicious case detected in HC #6 is in red. Figure illustrates those actors working as Agents in two HZ named Befale and Boende. The map represents the former Equateur Province.

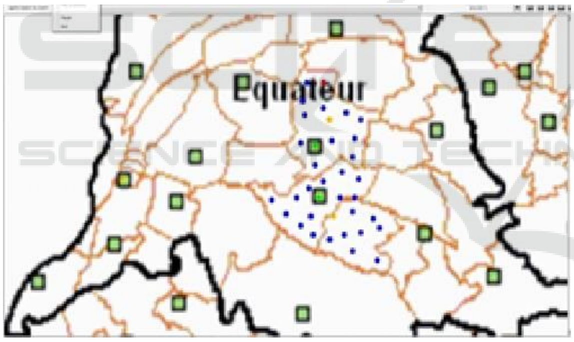

Figure 7: Collecting data system simulation in Befale and Boende.

The simulation trace file (Figure 8) shows the communication between the agents. As they are autonomous they perform their own tasks like "conduct an investigation" and manage messages like "receive sample to analyze" or "send suspicious case detected". The HZET Agents (#1 and #2) are waiting for a suspect case message from any HC. Whenever HZET Agent receives such a message he builds a RRT Agent able to investigate in HAs around suspect case. RRT Agent could send samples to LaboAgent while searching for new cases in HAs. The organization of outbreak riposte depends on the results from LaboAgent and investigation report from RRT Agent. .

The agents operate independently: RRTAgent completes a full investigation, LaboAgent conducts quality medical testing and PHD manages all informations from HZET under it supervision. Message synchronization between kinds of agent is done in the agent's decision loop. A protocol with two states is used and implements KQML-like performatives. The four numbers in the message are "1" for inform (give information), "2" for query information (ask for an information) and "3" for request (ask for a task to be done). The agents communicate and achieve their goal by reacting to messages from others or executing their inner task as response to a query.

```
01.387  2  HZETAgent #2  : Achieved Task: HZET 2  Wait for an Investigation request !

01.486  6  HCAgent #6: Achieved Task: Suspiscious case detected !
01.489  6  HCAgent #6: Sended message [6;1;0;1;0;0;0;Suspiscious_case_detected 6]

02.874  1  HZET #1: Achieved Task: HZET1  Wait for an Investigation request !
03.577  1  HZET #1: Received message [6;1;0;1;0;0;0;Suspiscious_case_detected 6]
05.005  1  HZET #1: Achieved Task: HZET 1 Ask RTT #38 for Investigation!
05.005  1  HZET #1: Sended message [1;38;0;3;0;0;0;Investigation_request 6]

07.463  38 RTTAgent #38: Achieved Task: Wait for an Investigation request !

07.463  38 LABOAgent #18: Received message [1;38;0;3;0;0;0;Investigation_request 6]

07.664  38 RTTAgent #38: Achieved Task: Go to the CS 6 zone !
07.664  38 RTTAgent #38: Achieved Task: Conduct the Investigation !
07.664  38 RTTAgent #38: Achieved Task:  Reports Suspicious Case ! : CS 6


07.865  38 RTTAgent #38: Sended message [38;1;0;1;0;0;0;Confirmed_suspiscious_case  6]
07.865  38 RTTAgent #38: Achieved Task:  Collect Samples !
07.865  38 RTTAgent #38: Achieved Task:  Transmit To a Laboratory !
08.008  38 RTTAgent #38: Sended message [38;3;0;2;0;0;0;Sample_to_analyse 1 38 6]
09.750  3  LABOAgent #1: Received message [38;3;0;2;0;0;0;Sample_to_analyse 1 38 6]

08.262  1  HZET #1: Sended message [1;37;0;1;0;0;0;Suspiscious_case_detected 6 1]

11.943  38 RTTAgent #38: Achieved Task: Investigation Reporting by RTT 38 about a case at CS 6!
35.556  38 RTTAgent #38: Sended message [38;1;0;1;0;0;0;Report_investigation 6 38]
35.556  38 RTTAgent #38: Achieved Task:  End Of Mission !

18.555  37 LABOAgent #17: Received message [1;37;0;1;0;0;0;Suspiscious_case_detected 6 1]

37.860  1  HZET #1: Received message [38;1;0;1;0;0;0;Report_investigation 6 38]
38.116  37 PHDAgent #37: Achieved Task: DP 37 Archives Case  concerning CS 6 from HZET 1
38.212  1  HZET #1: Achieved Task: HZET 1 Prepares response for CS 6

38.796  6  HCAgent #6: Received message [1;6;0;3;0;0;0;Apply_response]
39.186  1  HZET #1: Sended message [1;6;0;3;0;0;0;Apply_response]

39.631  6  HCAgent #6: Achieved Task: CS 6 Applies Response !
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Figure 8: Simulation trace.

7 CONCLUSIONS

In this paper, we presented how ABM can be used to monitor an epidemic outbreak in two Health zones (Befale and Boende). The process of collecting health data in health Zones and the response given by provincial and national levels were analyzed. A multiagent model for healthcare system in DRC has been built to represent the use case. This first experience of our research and the results described in the section 5 convince us that it is possible to make a social simulation of the real system. It's feasible to simulate the hierarchical organization of the administrative structures, to collect and manage health data from health system actors.

Our self-centric analysis and simulation give a promising result we would like to implement to a real system by making comparison with the manual process used to respond to an epidemic disease in DRC. With certainty, we have some perspectives to use the simulations. From the study of the current process and the analyses of its simulation, the process will be improved by extracting best practices for a subset of tasks and actors. This paper represents a first step and a positive sign that shows that the multiagent solution represents a good approach to help in decreasing the delay for riposting.

The multiagent model must be improved. At first, we are going to integrate analyses criteria on the agents like the response time or the agent's load that is the number of requests resulting from other agents to analyze the process and propose improvements. We should simplify or improve communication and information management. Applying enriched agents' behaviors will give us the opportunity to simulate an operational system with a new distribution of powers between agents so as to improve collaboration and shorten the response time between the actors.

A second axis of improvement is situated at the level of the interaction protocols. For the moment, the protocols described in section 4 have two states. The social behavior of the agents should be complicated by implementing for example a call for proposal in the appropriate situations (medical analyses in agent laboratory).

At the model level, additional work will be done on the organization: the information will not only be managed in a hierarchical way but with groups dynamically built with explicit criteria such as geographical location.

The last perspective is to couple the simulation system with embedded devices to collect data. A part of the agent perception should be the result of the automation of a portion of the process embedded in a phone or a tablet.

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