PANDEMIC DYNAMIC OBJECTS & REACTIVE AGENTS

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ABSTRACT

This paper proposes an innovative approach to pandemic models introducing agents for considering human behavior impact. The authors propose a methodology for developing these models as well as the related support features in relation to the open-issues generated by pandemic threats. Special attention it is proposed on providing a protocol for quick development and fast result achievement and concurrent strong attention to validation and verification .

Keywords: Pandemic, Health Care Modeling, Intelligent Agents, Human Beha

1. INTRODUCTION

Today there is a growing importance in quick model development protocols; in fact simulation it is often the most promising technique to investigate complex system and to face issues such as pandemics, however the development time required by this approach can result in critical and void its potential benefits.

Due to this aspects the authors propose a protocol, based on a lean simulation concept, for effectively and quickly modelling and analyzing pandemics

By the way in this sector, special attention is required for considering boundary conditions that heavily affect these phenomena such as human factors strongly affecting population reaction to possible countermeasures

So this paper proposes a protocol for exploring the dynamics of the spread of a pandemic by computer simulation, using a H1N1 influenza A virus as case study.

The authors start from analyzing an existing model such as EpiCast a computational model developed by the Los Alamos National Laboratory (LANL), used as part of the US National Strategy for Pandemic Influenza, and currently being used by the Department of Homeland Security to evaluate the current influenza situation in the US.

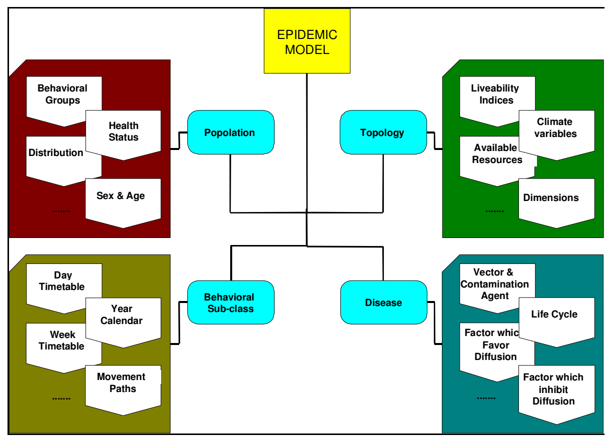

Figure 1 Example Epidemic Model Components

A critical aspect of models relates to the fact that basically they need really good data to be effective. In tbhis case this imlies:

modeling the virus itself, hopefully with additional information respect agent model and

modeling population (ethnographic) - knowing positively that someone is infected - it is necessary to go into detail on defining what data are available for defining the scenario

Therefore is important to model new elements in order to face current scenarios and to support decision makers in Government, Health Care and Institutions. In fact considering the Australian it is useful to extend existing models by including more realistic human behavior, which adapts as the pandemic spreads. It is also critical to develop advanced decision-support tools with enhanced data assimilation and visualization to support policy makers in formulating effective mitigation and intervention strategies.

Therefore the Australian case, given the population size of around 18 million represents an interesting and complex, but feasible example, for a nation size model.
Another very critical aspect it is the of supporting traii ning and accreditation in the use of the model by decision makers; today many models are providing pretty different

figures on these events, due to the fact that data are strongly changing the whole model behavior, so emphasis is needed on data certification and model development, consistently and concurrently, with the real system.

2. MODELING PANDEMIA

In a pandemic, there is a complex interplay between these factors but there are also significant variations introduced by the changing nature of the virus: in 1918 for instance, the virus had three waves

- mild
- moderate virulence
- severe virulence

but in the last phase it varied in its virulence from a low value of 2% kill to up to 20% kill of those that contracted the virus; this aspect it is similar in later pandemics 1957 and 1968 and more recently in the SARS; epidemic; recent varieties of H5N1 have had sometimes very high virulence - up to 50% killing and poor response to anti virals, in the case of H1N1 Australia, not only the virus can increase its virulence in waves, but it can also mutate in a way reudce the effectiveness of a vaccine an important considerations to be included in the epidemic model.

In an epidemic crisis - the starting point , the waves of the events - usually at least two, the end point are harder to determine. Therefore the epidemic evolution effects include, health, transportation, economy governance: national versus global.

The overall strength of the defense strategies at this time are depend on the resilience of vaccines and anti-virals. In the next wave with adverse mutations the virus will get more virulent maybe 5 to 10% mortality and could become more mutable meaning that a vaccine would not work and the virus could adapt to the anti virals so their effectiveness would go down. A virus that is causes no symptoms the several days, but is infectious - is hard to treat with current antivirals which are most effective in the first 48 hours.

Thus key is to track the population, put in place personal isolation measures (isolation, restricted movement, masks, and when needed quarantine) - this requires advanced modeling and simulation, that includes physical response to the virus, behavior of people in populations exposed (who goes to work who stays home) and, in the future, genomics to predict who will get sick , who will die, and who in the population will not get sick.

Specifically, the proposed approach focuses on countermeasure effectiveness with realistic boundary conditions and people, government, institution, companies reactions; for instance modeling the progression of disease respect quarantining and the impact of intervention measures considering human reactions and factors by introducing intelligent agents. In order to proceed in this direction it is necessary to address the following epidemiological questions: (1) efficacy and cost benefit of various mitigation strategies such as school closures; (2) expected level of absenteeism, and the impact of absenteeism upon commerce, industry, and the economy; (3) identify at-risk groups and mitigation strategies which will protect those groups; and (4) risks and returns (benefits) attached to implementing different mitigation strategies across state borders.

This research brings together a state-of-the-art high-resolution model of disease spread with cognitive science and advanced computational techniques to create decision support tools for policy development.

The idea to model every individual member of the population to create robust evidence-based policy is a very innovative concept proposed by the authors.

In fact the authors propose in order to speed up the development of new models to consider as first step forward the development of the following extensions to the basic EpiCast framework:

- Including more realistic, adaptive human behavior. Existing differential equation based models have used very simple, non-adaptive behavior when modeling individuals. Capturing individual human behavior has been highlighted as an important modeling task . The authors' aim is focused on capturing people's attitudes and likely behavior during an epidemic through an epi-ethnographic methodology. This information then needs to be introduced into the model by introducing agents generating the diversity of human behaviors.
- Decision-support tools. Another important aspect is related to the necessity to significantly improve existing decision-support tools; the analysis highlighted the following actions: (1) development of a data assimilation framework to create real-time forecasts of disease spread; and (2) application of the latest visualization techniques to generate easy-to-grasp movies and visual statistics of epidemic dynamics for better communication with and between health professionals, policy makers and the community.

Some of the authors (Newth) acquired experience focusing on the first use of EpiCast in Australia with Australian data; therefore it will be a significant step forward in term of innovation to create a simulation at the individual person level at a nation level including adaptive human behavior and extensive ethnographic work on pandemic perception over time.

So the proposed model offers an integrated wide approach to managing the emerging pandemic; as compared to smaller localized agent based simulations.

In addition, this model captures a higher level of detail than what is offered by differential equation based approaches .

3. RESEARCH INITIAL APPROACH

Early epidemic models were based around systems of ordinary differential equations, with unrealistic assumptions of large populations and perfect mixing. A breakthrough in modeling occurred with the work by Germann et al. in which the entire US population of 281 million people was treated individually as the agents within an agent-based model (ABM). EpiCast combines detailed census data with travel data and disease transmission dynamics to quantify the dynamics of epidemic spread. The model now forms an operational test-bed for the evaluation of quarantine, vaccination and anti-viral strategies.

The analysis suggest to focus on four major directions in order to develop new simulator:

3.1 Creating Reference Scenarios

For instant based on proper configuration of existing simulators (i.e.EpiCast). This includes data collection; estimation of key social contact parameters from time usage data; sensitivity analysis; and baseline scenario analysis. This phase provides an opportunity for developing detailed scenario analysis, as per Germann et al., on the Australian context. In this phase the authors are also addressing the impact of absenteeism on small-to-medium businesses, regional areas and smaller communities; social reliance and sustainability of regional areas with limited access to support services; and economic impacts per-sector. In order to achieve this result it is necessary construct a scenario development tool (SDT), Pandemic Simulation Language, to aid policy makers in formulating scenarios. The SDT creates scenarios to be read by the EpiCast engine, so this subsequently could becomes the interface used by government and health professionals.

3.2 Ethnographic surveys.

It is necessary to define procedures and protocol for data collection; in particular it is proposed to proceed with data collection of the behavioral model in two phases with two foci. The first consists of interviews, the second, a survey to refine and validate the beliefs and intentions gleaned from the first phase. There is a focus on general attitudes and specifically workplace issues, including surveys within companies.

a) Interviews have to be conducted across the following dimensions: urban versus rural; income category; family status; professional category. Interviews have also to be conduced across the business sector to ascertain attitudes and responses to absenteeism. From these interviews behavioral rules are formulated in the form: if infection level is high, I would not go to work.
b) The set of rules in (a) is assembled into a web questionnaire, collecting a significant sample, with the quantifier as a response, yielding a probability distribution for behavioral choice. Considering Australia as a possible case study, the comparison between Sydney and Melbourne could help to ascertain attitude changes as the pandemic spreads. A key objective here is to capture the change in attitudes and behavior as the pandemic spreads, through people's direct experience, social influences and the media.
c) Interviews with the general public have to be carried out during new model development to identify specific issues related to human behavior and for validation and verification purposes. Following on from this, interviews with business about absenteeism could be conducted. The set of rules inferred from the interviews have to be embedded in the new models. Sensitivity analysis of the full model is the proposed methodology to check consistencies and to support verification and validation. The human behavior model needs to be extended in order to consider the survey data.

3.3 New decision-support and visualization tools.

It is critical to develop two key proof-of-concept decision-support tools, exploiting:

a) Data assimilation, an ensemble of statistical and computational techniques for the fusion of model and real-world observations in order to create forecasts — in our case, of disease spread. Data assimilation techniques are extensively used by weather forecasting systems, but can be adapted to any observable system regardless of its complexity or non-linearity.
b) Effective visualization tools taking the complex detailed information created by the simulation and make it digestible and communicable to the public. For example, visualization of the EpiCast simulation results has been used by Ira Longini to communicate the likely future course of flu spread in the US to the general public.

3.4 Comparative Analysis:

The current H1N1 pandemic has already shown unexpected dynamics; Australia results to be a strongly affected country as it is confirmed by the high per person infection rate and the concentration of cases in Victoria. Thus insights into the spread dynamics can be obtained from simulating different social structures. Preliminary simulation results of Melbourne, Sydney and Brisbane suggest that this is the case. Public transport usage, family and community involvement differ between country by country and it is critical for future pandemic model to consider comparative analysis over different geographical regions and nations. Tthis research involves investigators active in different sites: Australia, USA and Italy. For instance, in Italy social mixing in the home features much stronger linking across generations than is common in Australia or USA. These aspects provide interesting suggestion in modeling the pandemic behavior in term of identify open issues, factors to be considered and data to be verified and validated.

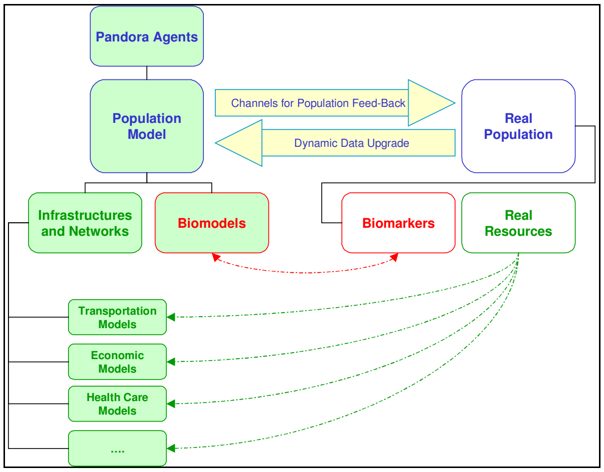

Figure 2. PANDORA General Architecture

4. DEVELOPMENT PROCESS

Basically the procedure is based on the concept to apply the following steps:

- Collecting data from on-going pandemic
- Add real data to the model
- Upgrade of the model
- Play into the behavior agents
- Comparing alternative choices simulating impact of resources costs, timer required for being activated/changes
- Evaluating impact of parameters that are estimated by SME such as casualties, deaths, severity of the disease, economic impact, impact on governance

In fact it is proposed the roadmap for facing a complex case study such as that one related to modeling H1N1 pandemic over Australia; in the following the authors provide a list of fundamental steps in order to achieve consistent results in this case in short time:

- Reconfigure Existing Models for the Case Study Australian context
- Design interviews and obtain ethics clearance
- Run existing models for a variety of contexts
- Develop extended model for interacting with decision agents reproducing human factors
- Carry out first phase of interviews
- Develop human factor agents
- Conduct second interview phase on company/workplace issues
- Run the new model including human behavior
- Analysis of socio-economic impacts
- Integrate workplace data and run full model

Each one of the above activities generates an outcome. The new configuration of existing models makes possible to simulate various scenarios from the basic original models.

Then the investigators, in close collaboration with officials, could run simulations and visualizations of spread and impact of outbreak under various scenarios. The reporting activity bring together the results of scenario analysis, ethnographic data collection and analysis. At this stage it is possible to carry out an evaluation of mitigation strategies with external stakeholders; following on from this, a detailed scenario analysis is conducted.

This models are expected to support several areas such as:

- Policy Definition and Regulation Revision
- Evaluation of Countermeasure Strategies
- Analysis of Quarantine Strategies
- Vaccine Management, Production and Distribution Policies
- Evaluation of Alerts and Tests Cost/Effectiveness
- Evaluation of new policies
- Effectiveness of Mitigation Strategies for reducing Virus Mutation Risk
- Definition Health Care Standing Operation Procedures
- Health Care System Reorganization
- Decision Maker Training
- Social and Economic Analysis

5. PANDORA

The main In addition to the proposed quick development process, it is suggest to develop a new simulation approach, defined PANDORA (PANdemic Dynamic Objects Reactive Agents), to incorporate the conceptual models and proposed approach within a common framework.

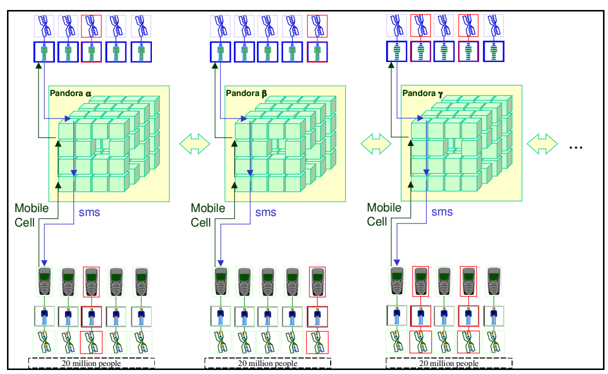

Figure 3a: Tracking each Individual by Clustering Regions

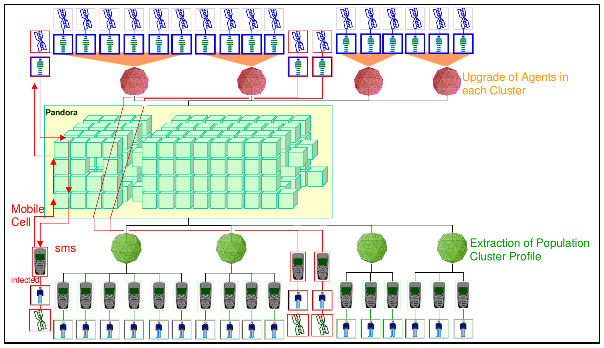

Figure 3b: Mapping Region Situation and Infected Tracking

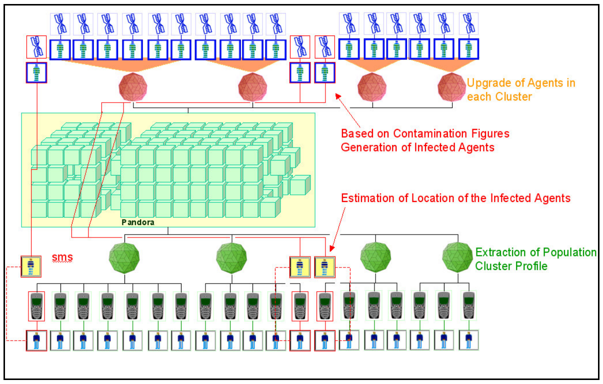

Figure 3c: Mapping Region Situation & Estimating Infection Source

PANDORA is envisaged as a decision support system based on simulation;to facilitate optimal choices before, during and after the pandemic, among the others these includes a number of key factors such as:

- security
- transportation
- food and water
- vaccinations
- antivirals
- Development of stand off detection systems
- personal distancing and protection
- masks
- quarantine
- isolation

For instance it is interesting to use these models to check if quick test with low cost and low reliability are more effective on the general behavior than more precise tests, considering people reactions.

The distribution of antivirals is itself a critical issue, currently being faced by the UK. There a web site and helpline provide immediate diagnosis and issue of antiviral from a collection depot. The effectiveness of this strategy will become clear in the coming months, but it is amenable to simulation.

In fact this represents a strong innovation directed to develop new simulators interoperating with different components in order to properly reproduce pandemic and to support countermeasures.

In this case the solution it is based on on-line stochastic simulation in a closed loop with live systems as proposed in the general architecture in figure 2:

- Population Models: Models of the individuals, groups and entities that correspond to the population all their characteristics
- Infrastructures and Networks: Modeling the environment, transportation, facilities and their characteristics
- Agents directing People Behavior and Human Factor
- Dynamic Data Upgrades: Channels for collecting on-line the situation of the people and their situation (i.e. mobile phones)
- Channels for Population Feed-back: Solution to provide directions to people in individual and group term (i.e. media, mobile phone)
- BioModels: Devoted to model genomics and diseases for reproducing their correlation for and supporting the estimation of probability to develop the infection as well as the relative evolution
- BioMarkers: Information allowing to identify individuals in term of their configuration, attitude and probability for being affected by specific infections

In fact by this approach it becomes possible to track the population; future experiments should direct to identify the proper granularity respect alternative solutions summarized in figure 3: in this case it is possible to have individual tracking within regions organized hierarchically (fig.3a), extraction of general parameters from the population and tracking of critical identified elements (fig.3b), or just group areas with injections of agents for estimating the most-likelihood situation of threats (fig.3c). It is necessary to point out that the three schemes are not alternative, in fact it is possible to think on combined solutions; for instance the above mentioned figures represent just tracking and communicating hypotheses through mobiles phones, however other communication channels could be characterized by different resolutions, in addition non cooperative behavior from individuals could necessiate a mixed configuration.

Therefore even with a so effective tracking of the population, if it will result possible by technical, legal and operational point of view, it is evident that the pandemic simulation needs to be able to look forward; these phenomena evolves, as already mentioned, quickly with strong inertia and influence of stochastic aspects (i.e. mutation, human decisions); for instance even instructions directed to single individuals or groups could be easily not respected: i.e. request to stay at home could be ignored by subjects due to underestimation of the related risks or due to personal interests in going to some relevant event (work or social activities), or even for fear to be framed in critical situation (in case of high mortality levels). So while the proposed approach results very reactive and allows to keep on-line the simulator with the real situation, intelligent agents represent the critical aspect for being able to project over the future scenarios evaluating risks and possible impact of decision, events and stochastic factors on pandemic evolution.

6. HUMAN BEHAVIOR AGENT

Modeling humans represent a challenge; in pandemic this issue introduce the necessity to include at least influences such as: perception of the threats.

Among the others these agents need to demonstrate both rational and emotional capabilities; the intelligence of these agents is limited to operative decisions, and it should be simple enough to face the challenge of the problem size related to a national wide simulation. Specific features and aspects need to be defined, modeled and tested in order to verify the capabilities of this intelligent agents respect the need of the epidemic simulation.

In fact among the others the following measurable characteristics are required to PANDORA Human Behavior Agent combining intelligence and emotions:

- Capability to move and interact with other ones based on the current situation and individual profile
- Capability to be configured based on specific parameters: i.e. physical, social, ethnic, religious regional aspects
- Capability to change individual profile based on the situation evolution
- Capability to demonstrate awareness of the current situation
- Capability to demonstrate effect of phenomena as:
- Social Network Attractors (i.e. family, friends)
- Stress, Fear, Fatigue, Agressiveness Evolution
- Effect of the group/social contents on the behavior
- Effect of media and communications
- Effect of economic situation
- Effect of Physical situation
- Effect of Emotional Situation
- History affecting future behavior
- Hysteresis of human behavior modifiers
- Psychological State Evolution:
    - denial, anger, bargaining, depression, Acceptance
    - underestimation, fear, terror, habit
- Working Elements
    - Attitudes of employers towards absenteeism

It is important to note that in term of human behavior the media plays a big part and so it does the training; so evaluating not only the equipment and technical solutions but even the readiness and specific skills of the personnel and resource involved.

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7. CONCLUSIONS

This papers describes a framework for proceeding with fast prototyping of new models for facing pandemics. In fact currently the existing H1N1 pandemic provides a unique opportunity, due to the low level of lethality and the pretty good data collected to improve existing epidemic models and to bring together international scientists to tackle a pressing international problem. The approach outlined here provides a national scale integrated approach to evaluating mitigation strategies. Finally the proposed

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models aims to deliver proof-of-concept modeling and decision support tools that can be taken to production and implemented within the public health sector.

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