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Agent-Based Models for Influenza Epidemic Dynamics and Its Decision-Making Capability

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Abstract

Agents-based models (ABMs) become more and more popular in applied mathematics During last 15 years a large number of ABMs have been created and used in different scientific area (ecology, economy, epidemiology, human behavior to name a few), but in this paper, only ABMs for influenza epidemic/pandemic dynamics in cities are considered in detail Based on a critical review of currently accepted ABMs of such special type new ABM has been proposed Unlike the old ABMs, it can be used for analysis of efficiency and cost of all interventions (how for ones had been carried out before and during epidemic or pandemic under consideration and ones that could be implemented but had not been carried out for some reasons) Moreover, under some conditions, new ABM gives us an opportunity to analyze efficiency and cost of different interventions for future oncoming epidemics (first of all pandemics) and to select its optimal combination

Keywords: Administrative decision; Agents-based model; Influenza epidemic/pandemic; Interventions

Introduction

Agents-based models (ABMs) become more and more popular in applied mathematics During last 15 years, a large number of ABMs have been created and used in epidemiology These ABMs have been created on the base of an agent's contact network that in its turn is created from demographic and infrastructural information about city or area under consideration Unknown, probabilities to get infected during contacts of infectious and health residents have to be defined from information provided by surveillance centers for different age groups The first ABMs for dynamics of infectious diseases appeared at the very beginning of this century **[1-4]** Unfortunately, both these pioneer papers and many subsequent papers contain several false suppositions and mistakes that led only to qualitative results for dynamic of epidemic/pandemic under consideration A level of uncertainty of such results does not allow recommending any quantitative interventions that could contribute to decreasing number of infected residents during the epidemic/pandemic In this paper, a critical review of currently accepted ABMs of such special type has been carried out and new ABM has been proposed.

Critical Analysis of Old ABMs and Proposition of a New One

Let us for analysis's simplicity consider a creation of ABM for influenza dynamic in a city Probabilities for susceptible people from different age groups to get infected during a contact with infectious people have to be evaluated from the patterns ie cumulated attack rates (numbers of infected people from the beginning of epidemic/pandemic) as functions of time for different age groups This standard data are provided by city's epidemic surveillance center.

- In the pioneer ABMs (and in many subsequent models)probabilities of being infected in the different types of working places (daycares, kindergartens, schools, institutes and other working places) and households during a contact with infectious person are used as model's parameters.

However, the standard data providing a city's surveillance center ascertain only the number of infected people during a day (or week) and do not contain information about where infections took place or who infected whom Since it is impossible to get information about something from nothing one does not able to evaluate such model's parameters with the help of the standard patterns.

The only parameters of a model that can be identified from these patterns are the probabilities to get infected anywhere during a contact with an infectious person from any age group These probabilities are different for different age groups and we will use them in the new proposed ABM.

- In most proposed ABMs model's parameters are evaluated with help of several numbers extracted from available patterns (for example, cumulated illness attack rates in age groups for the whole duration of an epidemic/pandemic).

Being integrals over the lower level of agent population such numbers do not have a unique and exact relationship with model's parameters It means that we have to compute dynamic of the epidemic with our ABM for defined values of model parameters at first and then to check the correspondence of the obtained values of cumulated illness attack rates in age groups to given ones Therefore, the evaluation based on such numbers generates a no unique selection of model parameters' values that correspond to these numbers. This problem of model parameters' evaluation is an ill-posed one (for any ABM!) and has to be solved by special methods only **[5]** the method of regularization, proposed in that paper, will be used in the new proposed ABM.

- In the proposed ABMs the reproduction number R_0 was used as the only parameter describing a solution in heterogeneous case Moreover, conclusions of Kermack-McKendrick's homogeneous model were declared (without any proof) equitable in a heterogeneous case In paper **[3]** made an attempt of proofing based on Diekmann's theory for non-overlapping containments; however in ABMs for influenza dynamics always there is a very important containment "households" populated by citizens from all other containments) It is well known that the no dimensional solution of any heterogeneous problem must depend on all no dimensional parameter of the problem under consideration **[6]**, in our case on all model's parameters Many investigators have already paid attention to this incorrect assumption **[7-9].**

In the proposed new ABM we refuse from the reproduction number as an index of epidemic severity level for comparing ABM solutions for different intervention strategies or different ABMs for the same city it is very convenient to use part of citizens who became ill during an outbreak.

Checking The Working Capacity Of The New ABM

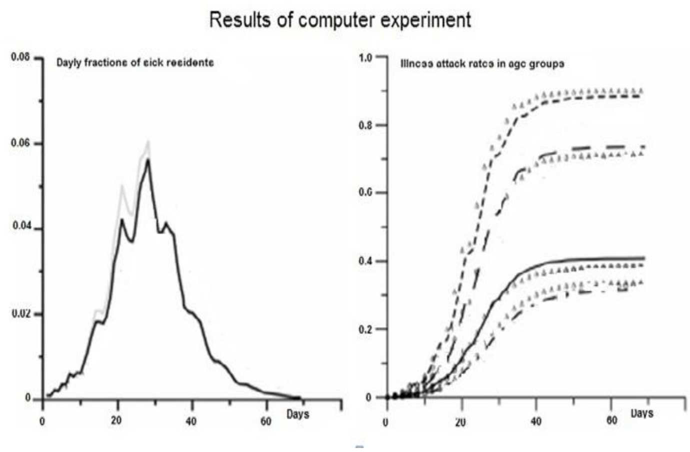

Figure 1: Checking the working capacity of the new ABM.

New ABM has been checked with the help of following procedures in **(figure 1).**

- For contact network of Dresden (Germany) and arbitrary values of probabilities to get infected in 4 age groups daily fractions of sick residents (black line on the left picture) and illness attack rates in all groups (lines of different types at the right picture) have been calculated ("exact solution");

- For these exact illness attack rates and other initial set of probabilities values to get infected the regularization problem of Tikhonov was solved New values of probabilities to get infected in 4 age groups were calculated For these new probabilities, daily fractions of sick residents and illness attack rates are compared with "exact" ones by a grey line and triangles correspondingly.

Discussion

The new proposed ABM reproduces quite well both the epidemic dynamics for whole city and epidemic dynamics in age groups Therefore, we now can use it for analyzing an effectiveness of any interventions both those that have been done during the epidemic under consideration and those that may be done evaluating simultaneously cost of all these interventions if corresponding prices are available of course, preliminary analysis of ongoing epidemics or, more important, ongoing pandemics would be a much more interesting possibility For the first time the new proposed ABM gives such an opportunity under two main conditions.

- One has all history parameters and outbreak dynamics for completed pandemic under consideration in some another city (source-city).
- There is a time-gap between outbreaks in two cities.

Often surveillance centers in different countries (even sometimes in the same one!) use for watching a different number of age groups In such a case we have to create the same age groups in the city under consideration Note that it would be more radical and more helpful to save age for any case of infection in a surveillance centre Such a format of keeping information would allow creating any number of age groups and this fact can be used for their optimization If so, one can construct contact network for the source-city and with the help of new proposed ABM to evaluate probability values to get infected during a contact between susceptible and infectious persons for different age groups Knowing these probabilities one can simulate future outbreak dynamics in the city under consideration Many possible interventions can be checked before outbreak and the best of them can be proposed for subsequent realization before and during the future outbreak.

Concluding Remarks

As result of critical review of currently accepted agents-based models (ABMs) for influenza spreading in cities new ABM has been proposed It can be used not only for analyzing results of past epidemic but for analyzing (under some conditions) ongoing epidemic/pandemic and optimization effectiveness of different possible intervention These possibilities of new ABM have been demonstrated at a test case of epidemic in a city For practical application of new ABM the results obtained must be confirmed at the real epidemic and pandemic.

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