Integrated Extended SIR-type Epidemiological Modeling Platform for Covid-19

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***Abstract*— In these conditions of Covid-19 pandemic, the design and implementation of an epidemiological modeling platform with an API-type integration with beneficiary entities and data providers is a priority for the healthcare system and other organizations. An epidemiological platform (PLIS), replicable and adaptable for managing an epidemic, based on an integrated extended SIR-type model, is presented in this paper. This solution has an open architecture, respecting the scalability and interoperability, requirements, and is based on international communication standards and protocols, and SOA technology.**

Keywords*— healthcare; COVID-19; epidemiological modeling platform; differential mathematical model; extended SIR-type model

I. Introduction

Internationally, an effort is made "to optimize the flow of data and information for the management of health systems, as studies show that medical and economic efficiency is strongly influenced by the level of development and complexity of implementing an integrated monitoring and modeling system epidemiological" [1] – [18].

In Romania, until June 4, 2020, a number of 19,907 coronavirus infections were confirmed. In total, 1,299 people infected with coronavirus died in Romania. The first confirmed case of coronavirus in Romania was announced on February 26, 2020. According to [2] "the northeastern Romania city of Suceava, the biggest Covid-19 hotspot in the country, was placed under lockdown as 593 Covid-19 infection cases were reported in the locality on March 30. The County Hospital in Suceava, one of the largest medical units in northeastern Romania, which serves a county with a population of about 600,000 people, will be closed on March 23, for disinfection after 52 doctors and nurses working there have been diagnosed with the new coronavirus (Covid-19). Given the gravity of the situation, the Health Ministry has decided to close the hospital and place all the doctors under isolation. In Suceava (first lockdown city in Romania), there was an accelerated community transmission, further developed against the background of many infected people and disconnections or errors both medical and of the local management, and against the background of an epidemiological investigation that was not finished, given that most of those who were supposed to undertake it or of those treating cases have been affected. At the same time, 1,299 Covid-19 patients died by June 4, 2020 while 153 patients were admitted to intensive care units. Throughout Romania, 2,363 people were under institutionalized quarantine, while another 96,693 were isolated at home. At a national level, 472,850 tests were carried out by the same date. Outside of the country, 3,084 Romanian citizens were diagnosed with the Covid-19 infection, most of them in Italy (1,699), Germany (583), and Spain (561). Since the start of the pandemic, 114 of them have died, while 22 recovered."

II. Integrated SIR-type Epidemiological Platform

In this paper an epidemiological platform is presented, replicable and adaptable for managing an epidemic, based on open-source software and computer applications. The platform allows "adaptation, customization and further development of IT applications according to the open-source principle, depending on the specifics of the public institution, the changes in the economic and social environment and the legal framework for its operation" [1]. The system is scalable, both vertically and horizontally and ensures functional decoupling of modules (while maintaining interoperability), extensibility and reuse of the facilities, and data security.

The proposed solution "ensures the fluidization of the information flow, the improvement of the resource management, the inter-institutional interoperability by offering a versatile, secure and resilient solution that can be customized according to the specifics of the public entities" [3]. The solution has an open architecture, respecting the scalability and interoperability requirements and is based on international communication standards and protocols, and SOA technology. The technical solution is scalable in terms of number of users, data collection locations (horizontal scalability) and electronic services and functionalities offered (vertical scalability). The solution has a high degree of parameterization and will cope independently with changes in organizational structure and process by beneficiaries.

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The epidemiological modeling platform (PLIS) developing include “an automated management of compliance with distancing/social isolation restrictions in quarantine areas, by geolocating and generating alerts for authorities in case of high concentrations or population dynamics, with highlighting risk areas and dynamic display on GIS maps (geolocation, dynamics, evolution potential, etc.)” [1]. The epidemiological model is based on the differential mathematical model extended SIR-type and the specific objectives were described in detail in reference [1]. The differential mathematical model of the extended SIR-type model is developed using Python programming language and involves the division of the population into three groups: number of infected people (I), number of people recovered (R), the number of people likely to be infected / susceptible (S). [1].

The extended SIR-type model is a dynamic system in three directions, for each variable (S, I or R) and varies over time [1]. The transmission rate is βI, where β represents the contact rate, and the possibility for a susceptible individual to come in contact with an infected individual and become an infected individual. Also, we have the recovery rate γ [1].

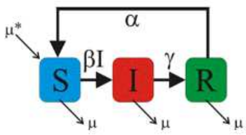

Fig. 1 SIR model [1]

In Fig. 1 is illustrated “an SIR model, where β is the contact rate, μ the death rate, μ* the birth rate, γ the recovery rate, and α the immunity loss rate” [1].

III. Epidemiological Modeling Platform and Results

The epidemiological platform (Fig. 2) allows the modeling and simulation of epidemiological evolution over time and is based on an extended SIR-type model [1]. The PLIS platform simulates the epidemiological evolution based on an existing epidemiological model or a user set pattern (Fig. 3).

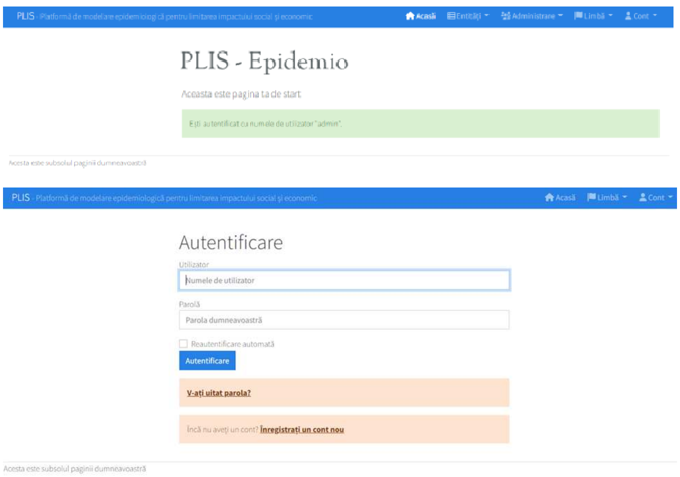

Fig. 2 The epidemiological modeling platform PLIS (screen captures)

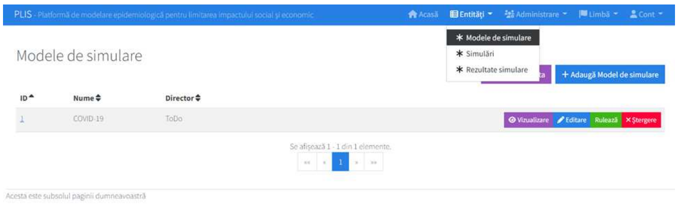

Fig. 3 Setting a model for simulation (screen capture)

In order to simulate an epidemiological model, the user has the possibility to enter the following fields: initial location (drop-down data), number of initial infections, simulation initial date (dd.mm.yy), simulation final date (dd.mm.yy), simulation step, transmission rate (β), the coefficient of non-linearity, recovery rate (γ), mortality rate (μ_i), immunity loss rate (σ), incubation rates (φ) (Fig.4).

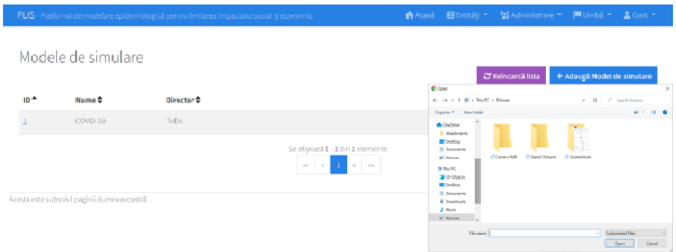

Fig. 4 Adding a new model for simulation (screen capture)

After entering all the required fields for the epidemiological model, the user can choose the "Run" option to initiate the simulation (Fig. 5). The indicators that can be viewed are the following: susceptible, exposed, infected, recovered, incidence, deceased, population. In order to consult the results of a certain simulation the user can access from the menu the option Entities and then Simulation results (Fig. 6).

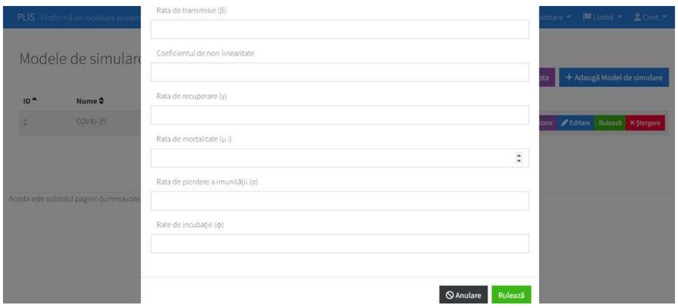

Fig. 5 Required fields for simulation of a epidemiological model (screen capture)

Through the mobile phone application (Fig. 7), people who have to comply with quarantine, isolation or self-isolation rules, will be able to be monitored from the location of the mobile phone. At different time intervals (set at random), the quarantined persons and those included in the isolation / self-isolation programs will have to send the location to the responsible centers. The location of the mobile phone can be transmitted automatically or manually. In case of transmission of a location that is outside the declared quarantine perimeter, an alarm message will be triggered [1].

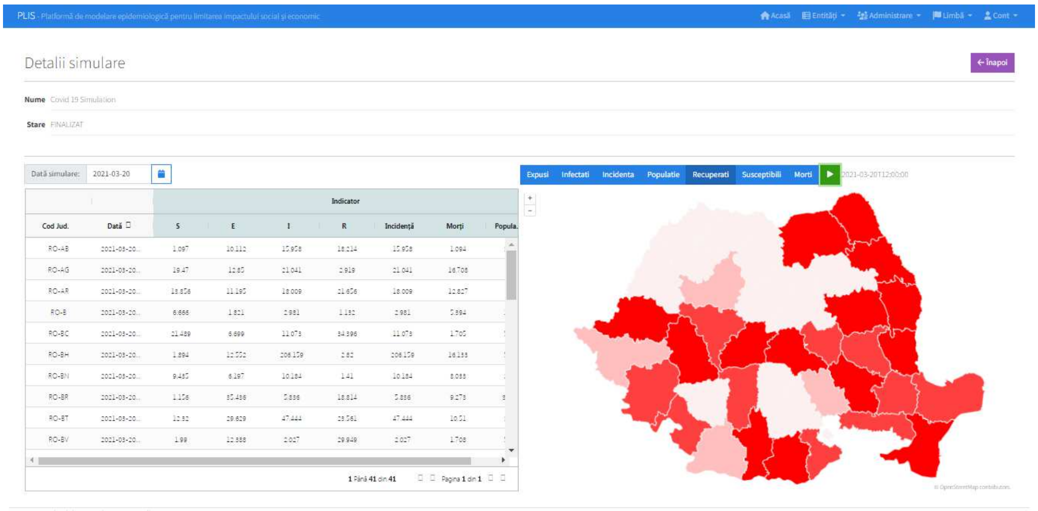

Fig. 6 Graphical visualization of the epidemic evolution on March 20, 2021 (screen capture)

The mobile application ensures the automated management of the epidemiological triage by including the functionalities regarding the online completion and verification of the epidemiological questionnaires (Fig. 7).

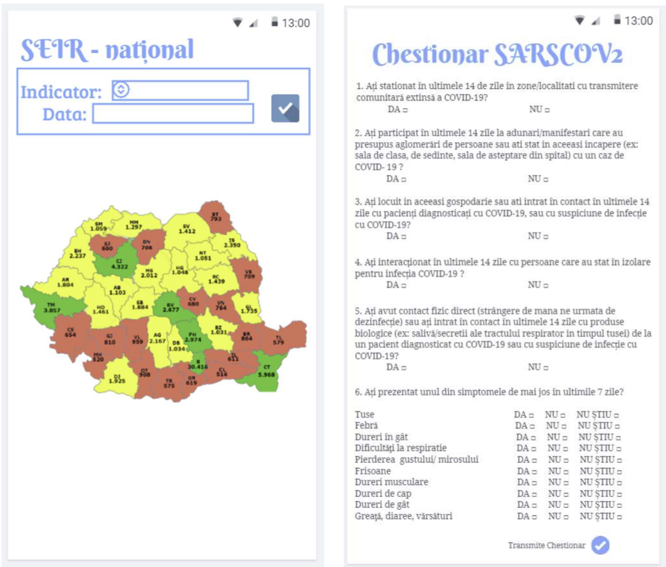

Fig. 7 Mobile application and geolocation functionality (screen capture)

The PLIS platform monitoring is carried out with the help of a special platform for this purpose, Zabbix™ platform. The monitoring process actively collects events from servers within the PLIS system architecture. The access is based on username and password and only from authorized IP addresses (registered at the server level - NGINX reverse proxy). Zabbix™ is an open-source enterprise-class distributed monitoring solution. Using Zabbix we monitored the parameters of a network, including the proper functioning and integrity of servers and also to provide reports and data visualization functions based on stored data (Fig.8).

The monitoring section is designed to display the summary of the important information. The Zabbix™ Dashboard provides customized high-level details about the monitored environment: favorite maps, favorite graphs, favorite screens. The monitoring dashboard consists of widgets and each widget is designed to display information of a specific type and source (Fig. 9), which can be a summary, map, graph, clock etc.

IV. Conclusions

The PLIS platform is adaptable to the specifics of any public institution for managing the epidemic situation, it is based on open-source software and IT applications, and allows the adaptation, customization and further development of IT applications according to the open-source principle, depending on the specifics of the public institution, the changes in the economic-social environment and those of its legal operating framework. The limitations of this platform are related to the fact that it was tested and adapted for Romania, which is organized by counties (the reference county is Suceava). We want to expand it to other countries or other pathologies. The platform is active with data per county, not on the locations that are part of the respective county.

The proposed platform monitors the evolution of different epidemic models. These models can be predefined and can also be modified by the user. Also, the user can create and save new models. The epidemiological platform allows the definition of specific pathologies in order to perform spatio-temporal simulations. The predefined epidemiological models in the application are: measles, rubella, hepatitis A, hepatitis B, seasonal flu, H1N1. Within the application for integrated epidemiological models, the following models were applied SEIR for modeling hepatitis A, hepatitis B, seasonal flu, H1N1 and SIR for modeling measles and rubella.

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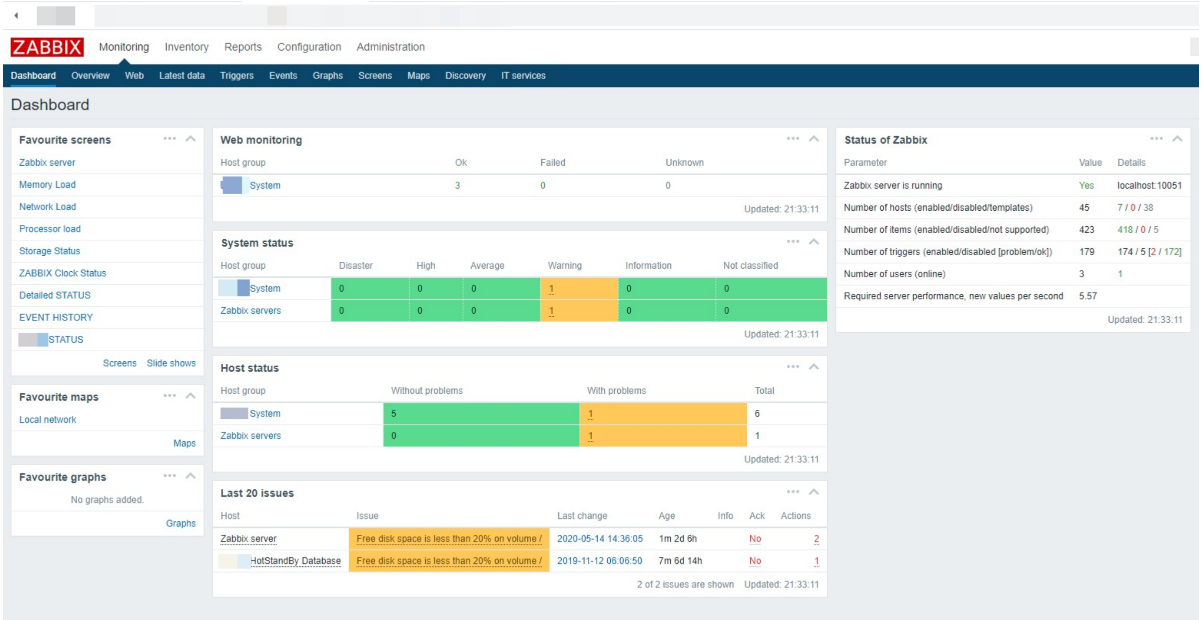

Fig. 8 Zabbix Monitoring Dashboard, (screen capture)

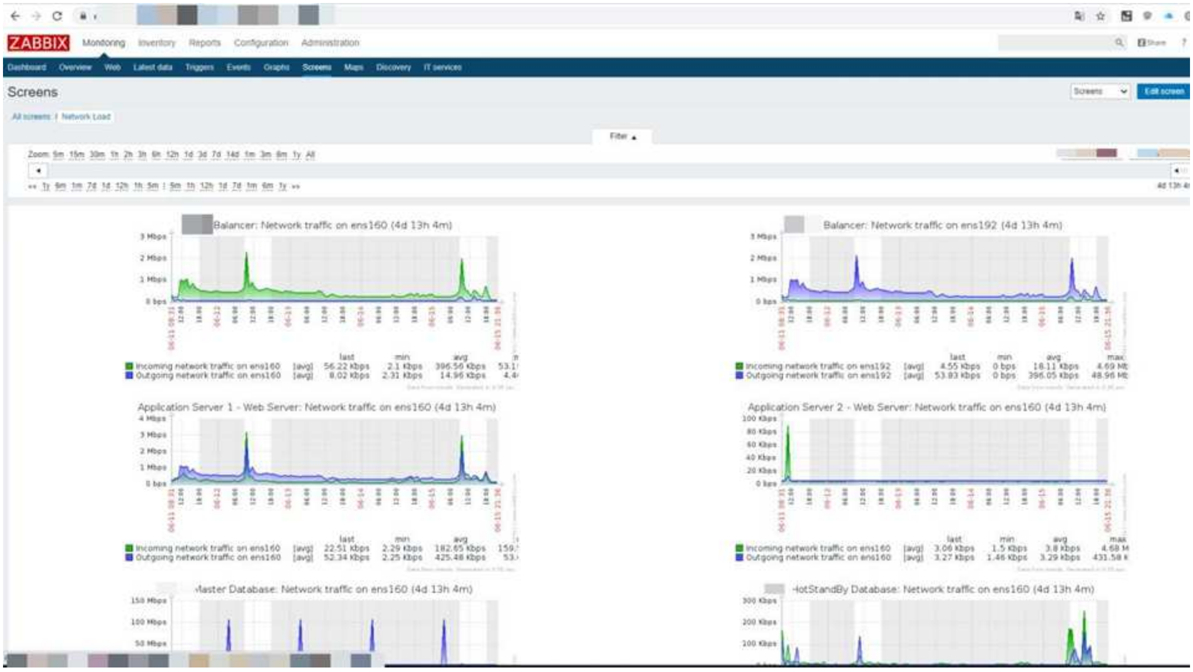

Fig. 9 Zabbix Monitoring Dashboard - Monitoring Communication network, (screen capture)

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