Toward Reference Architecture of Control System Socio-Epidemic Processes of Emergent Infections

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Abstract

The pandemic of COVID-19 showed the humanity is vulnerable to threats of epidemic emergent infections. Hence, the challenge of creating a safety system of the population from these threats at territory, national and international levels. The challenge poses a problem in the area of ICT consisting of that developing principles and techniques for engineering flexible decision-making systems. The paper presents a vision of an approach to solving the problem

Keywords 1

epidemic process, social process, spatial population flow, emergent infection, control of a process, anti-epidemic measure

1. Introduction

The pandemic of COVID-19 taught us a lesson that humanity is vulnerable to threats of epidemics emergent infections. It caused the understanding of the necessity of creating a system for providing safety of the population from such a kind of threats at different levels, territorial, national, and international. The challenge for developing such a system consists in the complexity of one. The complexity is a consequence of the necessity to take into account not only the epidemic process in progress but also the progress of related social processes. Moreover, we need to consider also the nature of the correlation of epidemic and social processes. This complexity is also associated with the fact that we need to make decisions in conditions of significant information uncertainty, which is caused both by the emergent nature of the infection and the difficulties of organizing the monitoring epidemic and social processes.

The COVID-19 pandemic has shown that the factors that make it difficult to control these processes are the necessity of:

- continuous monitoring of public opinion aimed at preventing the development of negative social phenomena and ensuring the effectiveness of anti-epidemic measures [1];
- adjusting the goals of anti-epidemic decisions depending on the amount of acquired knowledge and available tools to influence the infection [2];
- conducting explanatory and encouraging work with social groups concurrent with making decisions on influencing the state of public opinion [3];
- overcoming the contradiction between the extreme importance and low regulation of the information sphere in a democratic system, which sharply complicates the fight against fakes being naturally arisen and organized disinformation [4].

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Note that from the point of view of mitigating the consequences, an epidemic of an emergent infection goes through two phases. The first of these phases is the initial phase that is characterized by a low level of knowledge about the infection and by a lack of effective drugs. The second of these phases is the phase of the controlled epidemic process.

The initial phase operates with various strategies of non-pharmaceutical interventions during the spread of infection. For controlling pandemic COVID-19, different countries have used different policies for planning and using prevention and anti-epidemic measures following their socio-cultural, political and epidemic features. However, the main ones are providing physical distance; introduction of obligatory observance of hygiene and safety measures, as well as personalized measures of self-isolation and quarantine based on information about possible contacts with carriers of infection; providing adequate medical care; informing the public, risk assessment and activation of emergency management services; transport restrictions on both long-distance travel within the country and border crossings.

The World Health Organization (WHO) has been monitoring the pandemic on an ongoing basis (see Coronavirus disease (COVID-19), Weekly Epidemiological Update and Weekly Operational Update [5]). The relevant experience of implementing these measures was summarized in the document on measures against COVID-19 “Overview of public health and social measures in the context of COVID-19” on May 18, 2020, which recommended measures to slow down and stop the spread of the infection [6]. The measures are addressed both for individuals and for communities and institutions including local authority bodies, national governments and international organizations. The document proposed measures to control displacement, physical and social distancing, individual and special measures for special and vulnerable groups to slow the spread of the virus and prevent related diseases and deaths. Most countries have adjusted anti-epidemic measures in accordance with these WHO recommendations, which has ensured greater homogeneity of the list of measures, but differences in the organization and implementation of measures in different countries persisted. However, one and a half years after the beginning of the COVID-19 pandemic, there are still questions that need to be answered (see [7, 8, 9]):

- What are the stages of positive and negative effects of each of the anti-epidemic measures and their combinations?
- How do the spread of the virus and the economic losses from the introduction of anti-epidemic measures affect the level of social tension?
- How often does the infection develop with re-infection?
- What conditions contribute to the emergence of new, more aggressive variants of the pathogen?
- What conditions slow down, or even prevent, the development of infection?
- Why do people react differently to the pathogen (the disease in some is severe, and in others, instead, easily – in asymptomatic form)?
- Is it related to the conditions of transmission of the pathogen, the intensity of communication, other conditions?
- In what proportion of infected diseases occurs in asymptomatic form?
- What is the role of children in the spread of infection?
- Is the level of favor in children the same as in adults?
- What effect does each non-pharmaceutical intervention have?

These and similar issues are relevant not only in the context of the COVID-19 pandemic but also for any emergent infection. Therefore, we need tools to assess the reliability of responses to such an infection, based on estimating the interaction parameters between the structure, quality and effectiveness of preventive and anti-epidemic measures in emergent pandemic pathogens and also factors such as culture, political and legal system, economic status, social atmosphere etc., ensuring a balance between the effectiveness of preventive and anti-epidemic measures [10], and human rights [11] and its socio-economic well-being.

This paper proposes some architectural vision of an ICT-based technological framework to control the processes related to the challenges posed by the spread of an emergent infection.

2. Initial Prerequisites

The key prerequisite of the paper is the recognition of epidemic and related social processes as the single complex socio-epidemic process.

Let us consider this prerequisite in detail.

The following diagram in Fig. 1 summarizes further discussion

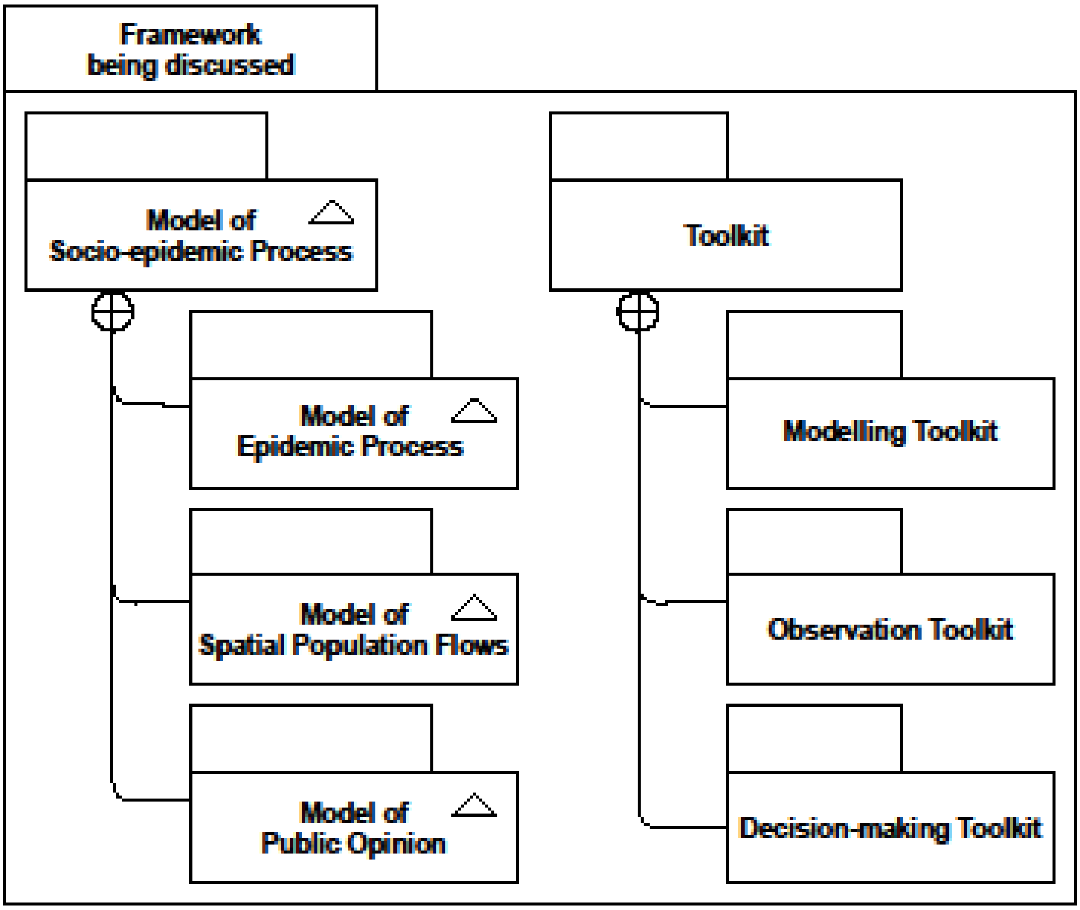

Figure 1: Composition of the proposed framework

Firstly, a generally accepted assumption is the assumption that the mechanism of the spread of any infectious disease is related to direct or possibly indirect contacts between people. The direct consequence of the assumption is a strategy of restricting the free walking of people for mitigating epidemic progress.

Secondly, the contact intensity of people depends on the intensity and structure of their social activity. Thus, social activity is an important constituent of a socio-epidemic process. Moreover, at the initial phase of the socio-epidemic process, we can impact the progress of its epidemic-constituent only with an influence on its socio-constituent.

Note. It seemed productive to use digital contact tracing technology to identify the sources of infection spread in the initial phase of the process, but the COVID-19 pandemic showed those expectations are inflated. The key reason is the serious contradiction between the information needs of anti-epidemic authorities and the legal guaranty of personal data protection. Unfortunately, no satisfactory solution for this contradiction has founded. A detailed discussion of the problem can be found here [12].

Thirdly, the above discussion shows to consider spatial population flows for recognizing hot spots for infection spreading. Taking into account the mentioned above contradiction, we need to be restricted by aggregated geolocation data, for example, data about the number of gadgets located in each spatial compartment in each time slot. Of course, such data cannot indicate contacts directly but can be used for estimating the number of contacts.

Fourthly, the efficiency of anti-epidemic measures depends on the commitment of the population to agree to the relevant restrictions, or, in other words, on approving these restrictions by public opinion. Of course, we also need legal media tools to influence public opinion to provide the necessary degree of community approvement of the anti-epidemic restrictions.

Another important prerequisite caused by the need to use concurrent threads to build and refine models of the socio-epidemic process, monitor the process or measure its parameters, as well as make a decision aimed at determining anti-epidemic measures being relevant to the current socio-epidemic state.

3. Basic Architecture of Framework

Our approach to developing a reference architecture of a control system socio-epidemic processes of emergent infections is to refine some basic architecture of complex object control systems using specific features of socio-epidemic processes. The origin point of our development is some basic architecture of control systems, the structural model of which is represented in Fig. 2. The core component of this architecture solution is **Decision Support System**. It computes a decision based on the observed state of **Control Object** and predicted one. The components **Monitoring System** and **Control Object Model** provides the observed and predicted states respectively.

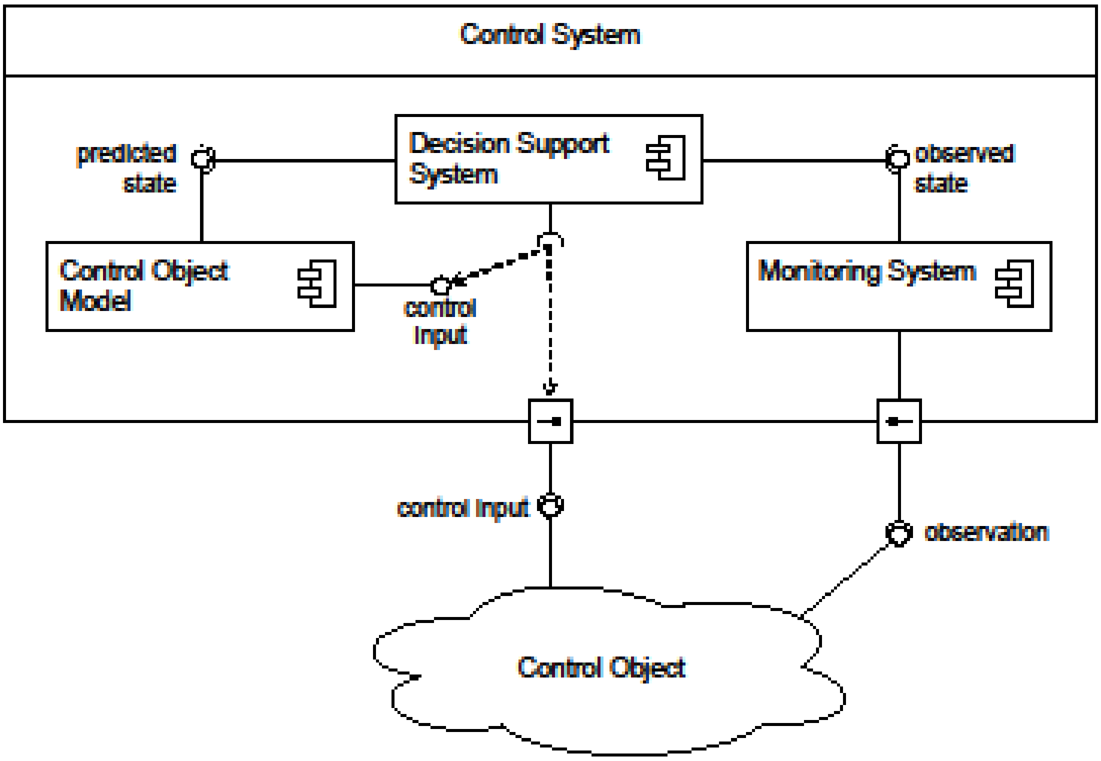

Figure 2: Basic architecture model of a control system

The system being described operates cyclic, loop-by-loop, and the corresponding control loop is shown in Fig. 3.

Let us refine the components of this model considering the above discussion (see Fig. 1). The refinement is as follows. The model of **Control Object** includes now four components, namely, **Spatial Population Flow Model**, **Epidemic State Model**, **Public Opinion Model**, and, finally, **Interaction Model** of these components. Of course, each of the first three models includes a model of its dynamics. In the time, **Interaction Model** ensures orchestrating these dynamics.

Similarly, **Monitoring System** should now provide tools for collecting data of three different kinds namely tools for collecting epidemiological and sociological data and the special tool for receiving aggregated geolocation data.

Taking into account the need to provide concurrent threads for refining models and decision making, we can use the strategy of reinforcement learning [13] for the management of the framework being discussed. We consider this approach the most adequate for the situation when the search space of a problem is not known beforehand or described by characteristics changing in time. Also, we need to mark the paper [14] dealing with a quite similar approach to the proposed one to analyze and predicting the progress of COVID-19.

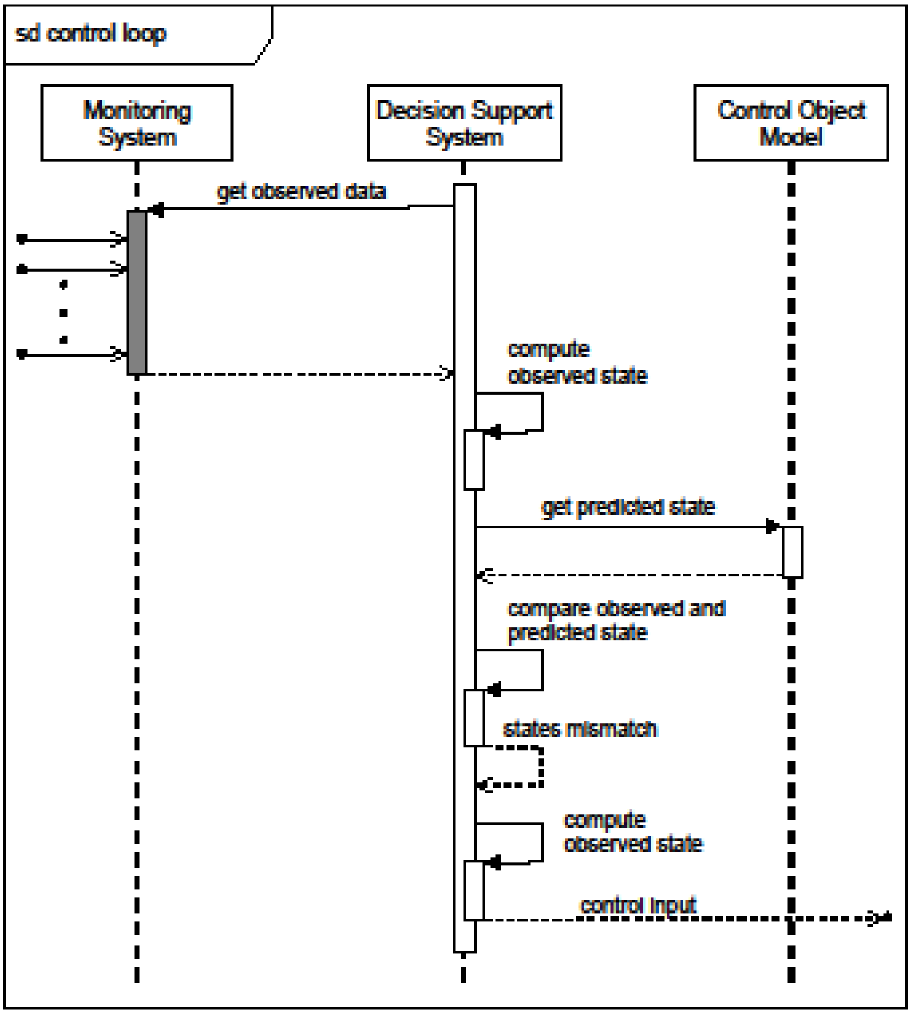

Figure 3: Basic control loop sequence diagram

4. Anti-epidemic Measure Decision Process

So, we are now ready to describe the general decision-making model regarding anti-epidemic measures aimed at mitigating the course of the epidemic of emergent infection, which ensures the fulfilment of the assumptions of Sec. 2.

Firstly, let us remind that we consider epidemic and related social processes as a single complex socio-epidemic process. Secondly, our aim is to provide a concurrent running building and refining the model of the process, monitoring (measuring) its parameters, and decision making epidemic measures. Implementation of concurrent execution is provided by the fact that we distinguish two layers of models.

Our vision of implementation of this concept is represented with UML 2 activity diagram shown in Fig. 4. Of course, loop B–B is the necessary adaptation of the general schema (see Fig. 3) to the context of controlling the socio-epidemic process of an emergent infection. Note, the proposed schema of decision making is open for implementing new knowledge about the controlled infection (see the port located in the bottom-right corner of the diagram in Fig. 4).

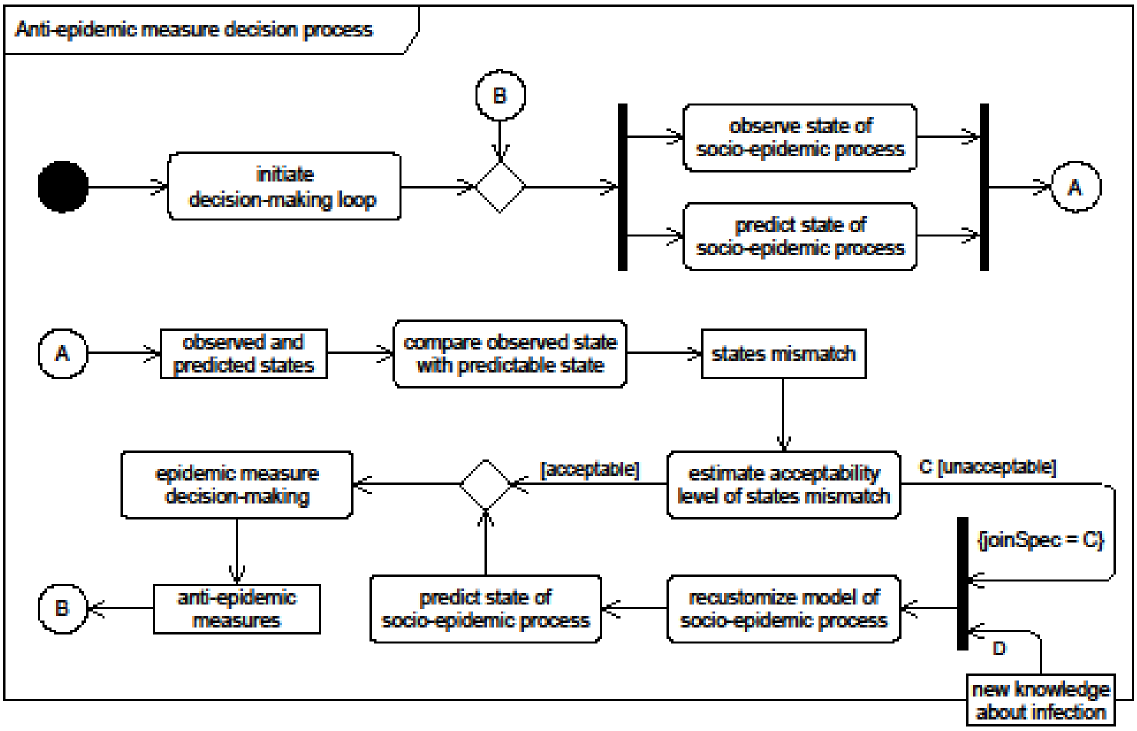

Figure 4: Activity diagram for an anti-epidemic measure decision process

5. Conclusion

The authors expect the construction of the described above framework provides a scientifically sound reference model and a set of mathematical, epidemiological, sociological and software tools that generally form a decision support system aimed at ensuring the controllability of socio-epidemic processes of emergent infections. Such a decision support system should admit the consideration of the features of a particular socio-epidemic process and administrative territorial unit. The core of such a system is a mathematical model of spatial population flows of the administrative-territorial units, with appropriate algorithmic tools to adapt the model to the conditions of a particular administrative-territorial unit and applied anti-epidemic and preventive measures. The system includes models of contact occurrence, which are adapted to study the dynamics of contacts in the spatial compartments of the model of spatial flows, which provides modelling of the general epidemic dynamics based on the compartmental approach. Appropriate simulation models are tools for forecasting the dynamics of socio-epidemic processes, including in the context of the introduction of new or weakening of existing anti-epidemic and preventive measures. A set of scientifically based methods of epidemiological and sociological analysis, as well as algorithms for accumulation and data processing of aggregate digital footprint, provides observation (measurement) of parameters to assess management criteria, in terms of adapting the model to the real socio-epidemic situation.

We expect results of the implementation of an appropriate complex of research and development provide

- taking into account different points of view on the socio-epidemic process to ensure the effectiveness of management decisions and control the level of negative consequences of anti-epidemic measures;
- stratification of the solution into system-wide and specific layers, which allows accumulating in the system information about the positive and negative experiences of epidemic management;

- tools for planning and implementing dynamic monitoring of the socio-epidemic process in critical areas to ensure the rational use of available resources;
- recognizing drivers of the epidemic process of emergent infection;
- the ability to take into account when making management decisions specific to different phases of the socio-epidemic process tasks and drivers of a particular epidemic process;
- the ability to integrate solutions with e-government tools.

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