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Formal Models of Sanitary Inspections Teams Activities

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***Abstract*—**This paper presents methods for formal modeling of activities in the area of sanitary inspectors outbreak of food-borne diseases. The models allow you to measure the characteristics of the activities of sanitary inspection and as a result allow improving the performance of sanitary services and thus food security.

***Keywords*—**Food-borne disease, epidemic, sanitary inspection, mathematical models.

I. Introduction

ACTIVITIES of sanitary inspectors during the epidemic of a food-borne disease are important from safety of our community's perspective. The aim of these activities is to detect and cut roads of spreading contaminated food as soon as possible. This paper describes the models of activities associated with detection and neutralization of threats. In addition, the models of spread of food-borne diseases are described.

The most important factor is the time the threat is detected and the time needed to complete the steps necessary to eliminate it. To improve the sanitary inspection teams operations, it is necessary to define some measurable characteristics that can be used to optimize these operations. This paper describes the models of activities associated with detection and neutralization of threats. In addition, the models of spread of food-borne diseases are described.

For the description of the activities of sanitary inspectors BPMN notation is used. The spread of food-borne diseases is described using Forrester's dynamic models.

The analysis of sanitary inspectors' activities led us to the separation of the two types of business processes. In the first group we have procedures for epidemiological investigation. The second group consists of the processes related to the concrete actions taken by sanitary inspection.

Forrester's dynamic models were developed for several types of food-borne diseases. Models were built, and dedicated packages were implemented to estimate models parameters based on actual data. As a result it is possible to simulate the spread of food borne disease.

Cost and time characteristics of business processes were studied. To investigate the characteristics of the process a dedicated simulation module was created. In addition, for the estimation of the Forrester's dynamic model parameters numerical procedures were built.

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II. Forrester's Model of Sanitary Inspections Teams Activities

The model of food borne diseases consists of several differential equations and has several parameters describing contacts of infected people with those which can become infected, probability of illness after such contact and so on. Furthermore, if one considers food borne diseases then parameters related to the pathogen concentration will appear. These parameters must be estimated and they can be influenced by people activities which aim at reducing the spread of the epidemic. In this section, we show how this influence can be modeled with the help differential-algebraic equations and how the model of these activities can be integrated with the model of epidemic. Such an integrated model should reflect the effectiveness of sanitary inspection team activities with respect to fighting off the illness.

To create the integrated model we use the Forrester's methodology for building dynamical models of complex systems [1]. The methodology was proposed by Forrester in late fifties of the previous century and initially was applied to describe dynamical behavior of activities of any organization, in particular industrial company. Later the methodology was successfully applied to any kind of human activities including decision making process.

According to the Forrester's methodology the model of a process is built in two stages. In the first stage main variables of the process are listed and the relations between them are stated. In that stage so-called Casual Loop Diagram (CLD) is constructed which reveals closed loops in the process which can be analyzed and used for the verification of the correctness of the process model. For example, if the process has variables which historical values show exponential growth, there must be at least one positive closed loop in the CLD of the process.

In the second stage the CLD of the process is transformed into a set of differential-algebraic equations. It is done by stating that some variables in the CLD must be differential variables which mean that there must be differential equations associated with these variables, the other variables of the CLD define algebraic equations. In the second stage to each variable (differential, or algebraic) some function (in general nonlinear) is assigned. At the end of the modeling process we have a set of differential-algebraic equations.

We start building the integrated model with the extended SIR (Susceptible-Infected-Recovered) model of epidemic. The extension of the standard SIR model includes the equation which describes how the amount of contaminated food changes in time – contact with the contaminated food leads to the spread of epidemic. The extended model has been obtained by referring to standard models describing the spread of epidemic [11]-[16]. The model is presented in Fig. 1. Notice that in the presented variant of the model we assume that infected population when recovered can again become ill. Moreover, we divide the whole population into two groups: *Popul A* and *Popul B*. While in the group A people can become ill by contacting infected people and by eating the contaminated food, people in the group B can only fall into illness through the contact with the contaminated food. The model in Fig. 1 has been created with the help of Vensim application [2]—the application uses rectangular boxes to denote differential equations and 'valve' symbols are related to flows. For example, the rectangular box described as *Susceptible Popul A* is equipped with the differential equation:

d(**Suscetible Popul A**)/dt = flow A = (**Infections C** + **Infections F**) - (**Recovery rate A** * **Infected Popul A**)

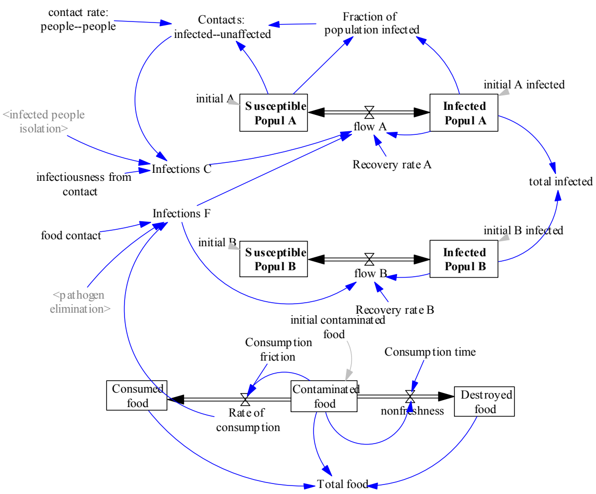

Fig. 1 The epidemic model of food-borne disease

The full integrated model of sanitary inspection teams' activities is given in Fig. 2. The integrated has several modules: 1) module related to the dynamics of epidemic-module shown in details in Fig. 1; 2) module which shows how the cost of sanitary inspection teams activities changes in time; 3) module which presents the mechanism of inspection teams creation, these teams should identify and then isolate infected people in order to contain the spread of illness; 4) module which shows how the sanitary teams are created with the aim of isolation of the contaminated food – this module is in principal very similar to the previous module.

The modules listed as 3) and 4) reflect some decision rules. Consider the part of the model which illustrates how teams for food inspections are set up. In Fig. 2 there are three rectangular boxes with which differential equations are associated.

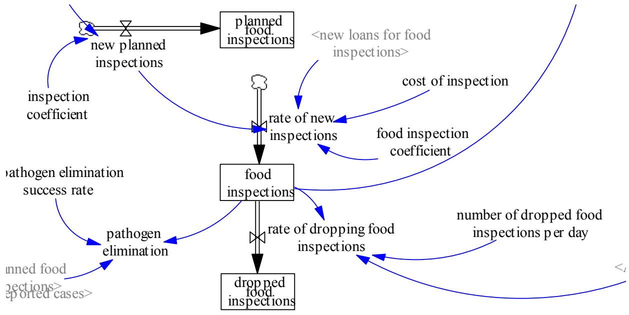

Fig. 2 The creation of teams for food inspection

The essential variable in this part of the model is variable rate of new inspections which has the following dependence tree. The value of this variable says how many new teams are created during assumed period of time. In the model we applied the following decision rule:

rate of new inspections = **food inspection coefficient** * (IF THEN ELSE(INTEGER (MAX (**new loans for food inspections** / **cost of inspection**, 0)) > **new planned inspections**, **new planned inspections**, INTEGER (MAX (**new loans for food inspections** / **cost of inspection**, 0))))

which can be read as: the number of new created teams depends on the available funds (new loans for food inspections) and the cost of creating the team (cost of inspection).

The module 1) and the modules 3) and 4) are linked with two crucial variables: pathogen elimination and infected people isolation. These variables assumes values in interval [0,1] and reflects the effort undertaken to fight the epidemic. If the number of food inspections is close to the number of planned food inspections then we reckon that the effort is well measured and the process of sanitary inspection teams is efficient. According to the decision rule the high efficiency of the process will be achieved if available funds are big enough. Therefore, the integrated model of epidemic can be used to verify the adequacy of the funds designated to sanitary team activities during epidemic.

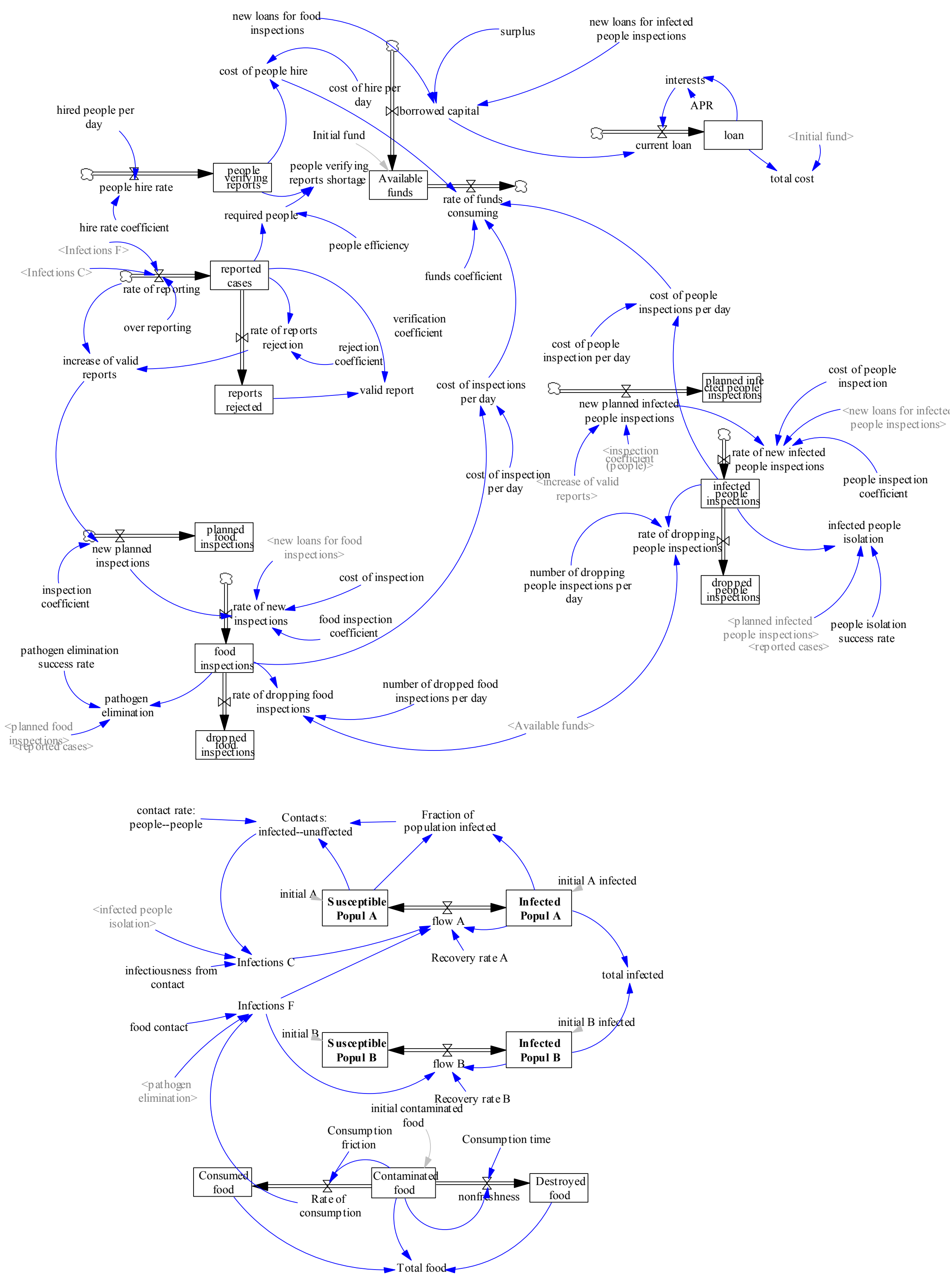

Fig. 3 Integrated model of sanitary inspection teams activities

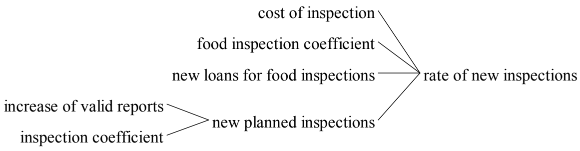

Fig. 4 Dependence tree for the variable **rate of new inspections**

In Figs. 5, 6 we show exemplary trajectories of some models variables. These trajectories were obtained by simulating the model. A model simulation is based on numerical integration of the model equations.

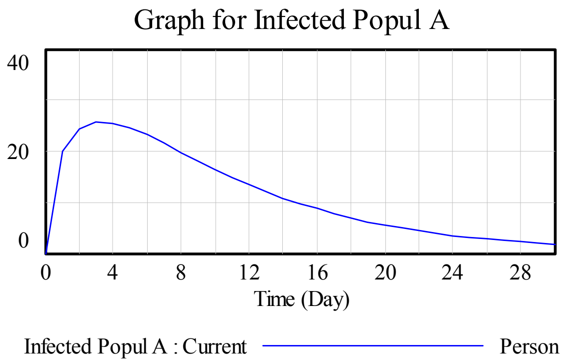

Fig. 5 Trajectory of the variable **Infected Popul A**

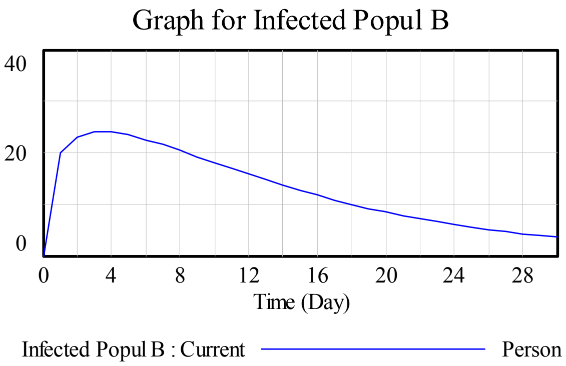

Fig. 6 Trajectory of the variable **Infected Popul B**

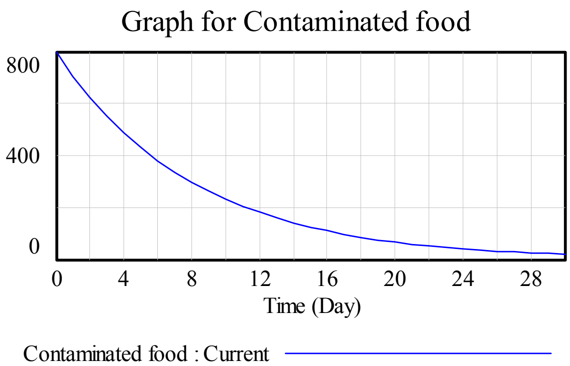

Fig. 7 Trajectory of the variable **Contaminated food**

III. Models Based On Business Process Notation

While modeling the state sanitary inspection functionality we should try to construct business processes of sanitary inspectors' activity. Then we must consider not only organizational structures of sanitary inspection organization but resources which should be taken into account as well. Business processes investigation can be conducted in order to obtain static or dynamic characteristics of sanitary inspection activity. This is a typical approach in the study of the organization based on the properties of the model analysis. In these sections we present business processes of functioning sanitary inspection in the case of a food-borne diseases epidemic. The main idea is how to investigate dynamic characteristics of business processes.

The process of planning sanitary inspectors' activity in the case of epidemiological investigations can schedule epidemic activities and services during epidemiological investigations. Business process corresponding to actions during the epidemiological investigation is presented in Fig. 8.

The advanced programming environments are developed in order to support modeling of business processes, their simulation and analysis. Among popular programming environments we can distinguish the AG Software ARIS, IBM WebSphere Business Modeler, Corel iGrafx, Sybase Power Designer, Aurea BPM, and others. In most of them it is possible to simulate business processes in order to obtain the dynamic characteristics of modeled operations [3].

Analysis of the system can be done in two ways:

- static analysis - made on the basis of inspection of business process diagrams of the system,
- dynamic analysis - the system is analyzed on the basis of the conducted simulation experiments that allow us to explore the dynamics of its operation.

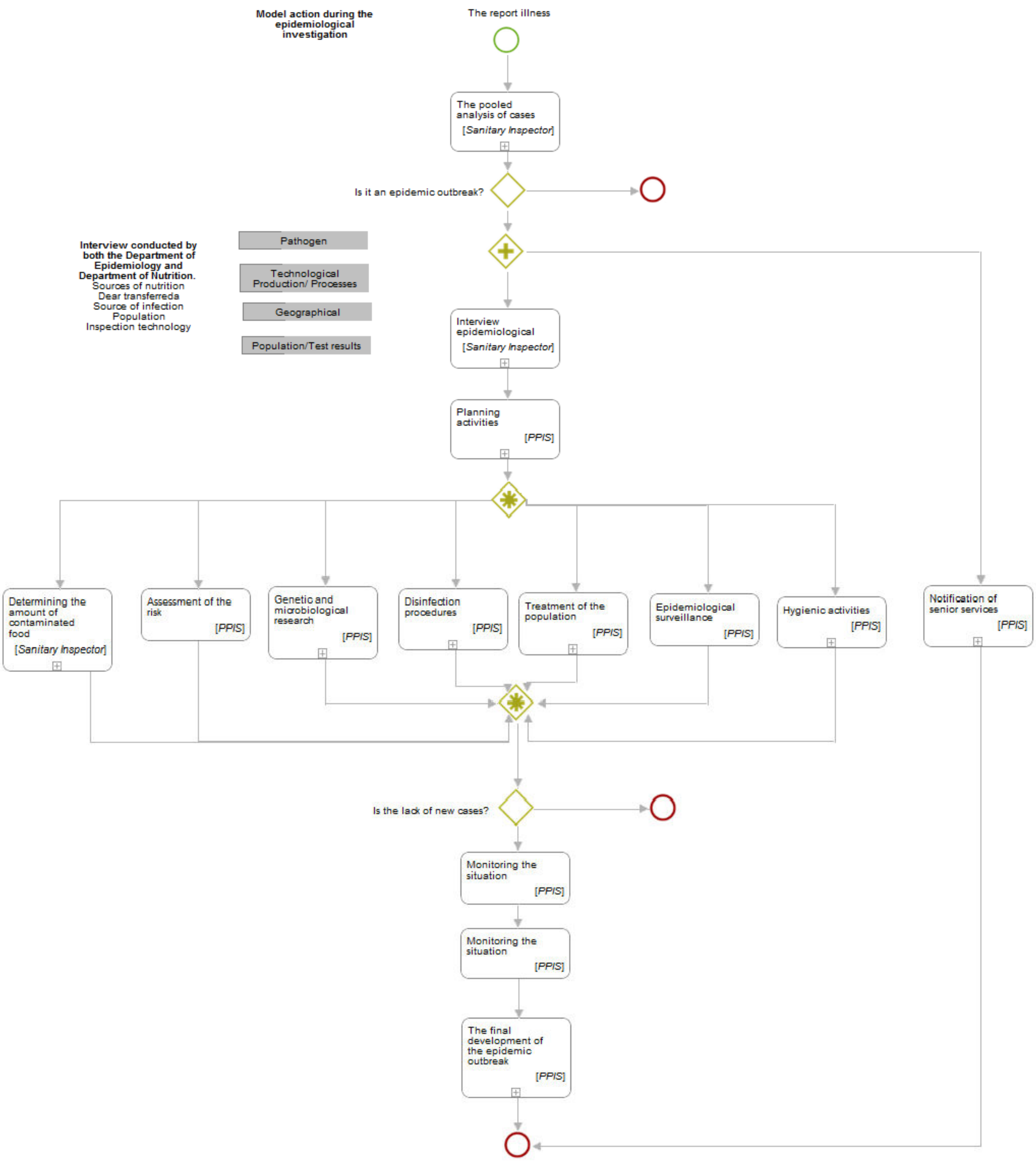

Fig. 8 BPMN diagram for planning sanitary inspectors' activity during the epidemiological investigation

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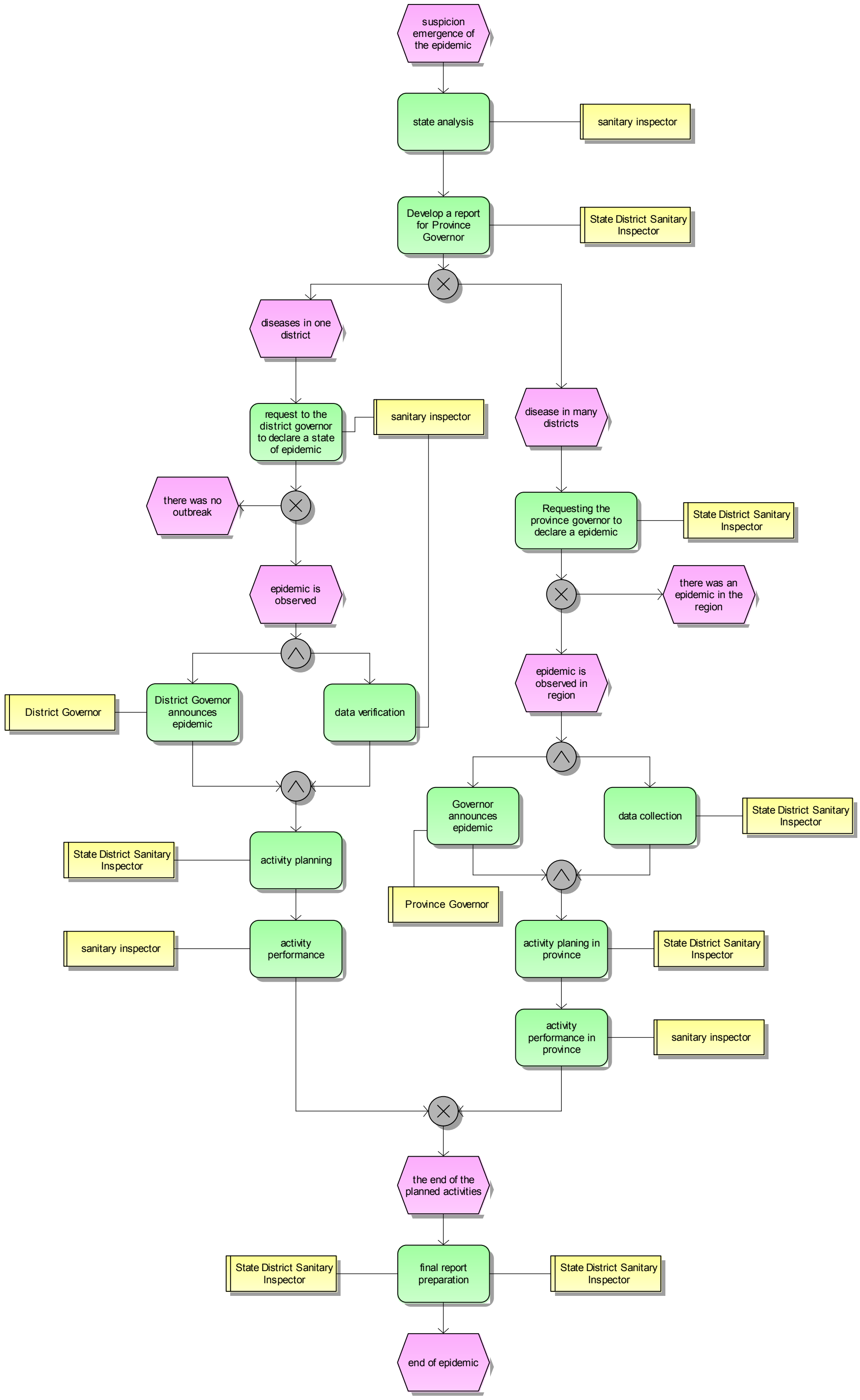

Fig. 9 Business process diagram for planning sanitary inspectors' activity during the epidemiological investigation prepared in ARIS

The model of planning sanitary inspectors' activity during the epidemiological investigation was created in a software environment ARIS, where the simulation of operations relating to the planning of sanitary teams activities was carried out (Fig. 10).

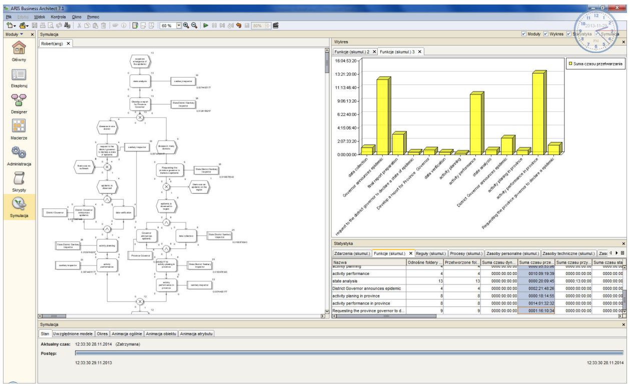

Fig. 10 Modeling and simulation environment ARIS

As a result of simulation experiments a number of interesting parameters related to the functioning of health services were obtained [4]-[10]. There is no possibility to obtain these parameters in the static analysis of a business process. They can be only determined by the dynamic analysis. A sample result shows the frequency of the various significant events during the epidemic (Fig. 10).

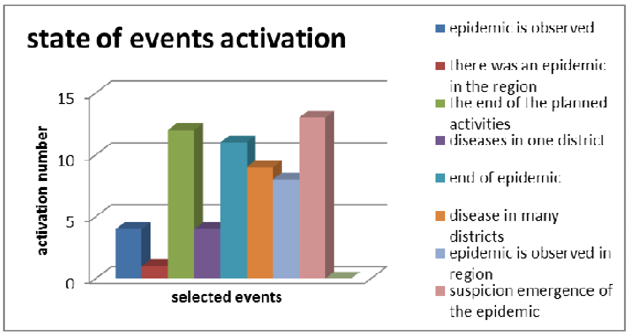

Fig. 11 The state of different events activation during the epidemiological investigation

The same can be shown for the frequency of the various significant activities observed during the epidemic (Fig. 12).

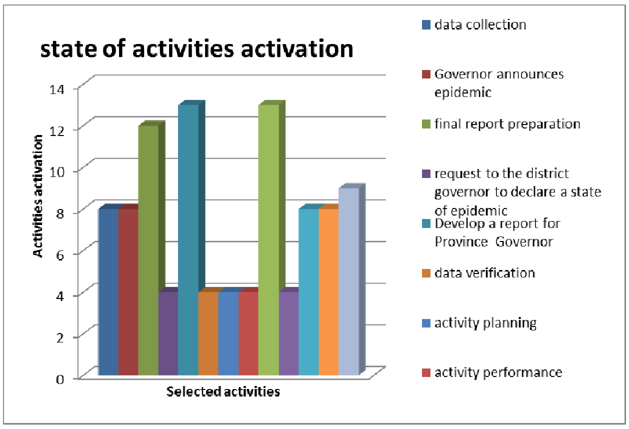

Fig. 12 The state of different activities activation during the epidemiological investigation

It is also possible to show simulation results connected with accumulated time corresponding to activities performance during epidemic (Fig. 13).

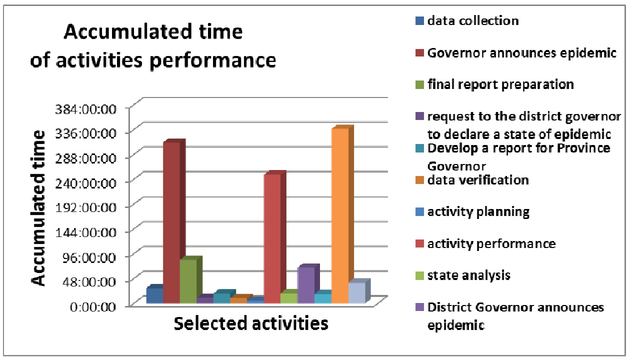

Fig. 13 The accumulated time of activities performance during the epidemiological investigation

Very interesting for further analysis can be the number of actions being performed by different people during epidemic (Fig. 14).

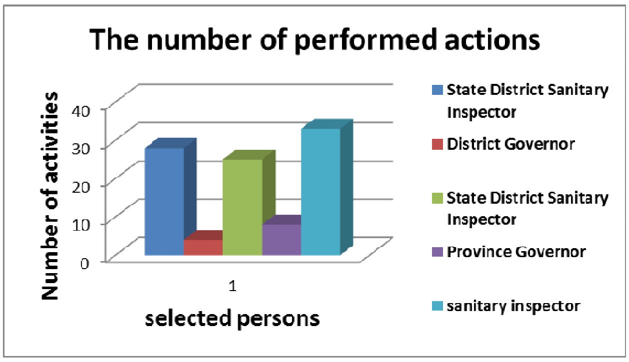

Fig. 14 The number of performed actions during the epidemiological investigation

Another question is how long different people were working during epidemic (Fig. 15).

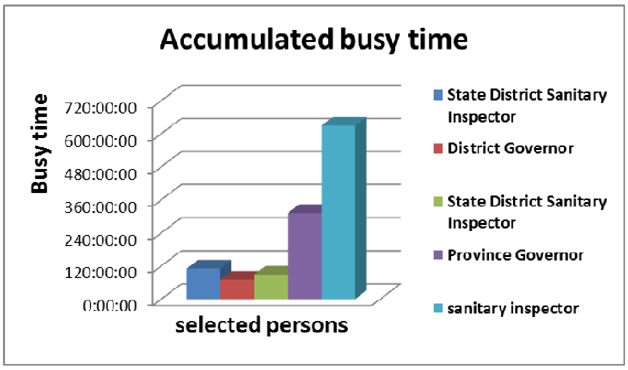

Fig. 15 Accumulated busy time of people during the epidemiological investigation

Practical question is how we can estimate the degree of human factor use (Fig. 16).

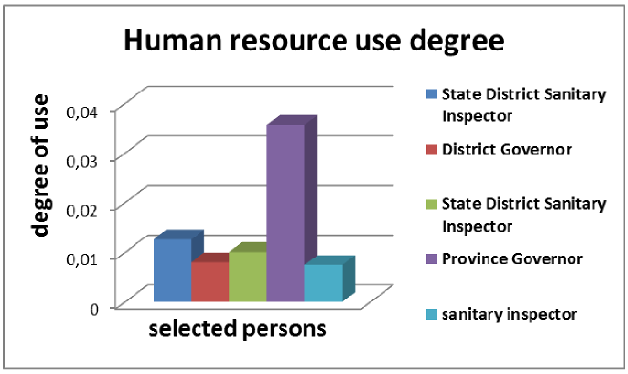

Fig. 16 The degree of human factor use during the epidemiological investigation

The last question is how to estimate global cost connected with sanitary inspection activity during the epidemiological investigation (Fig. 17).

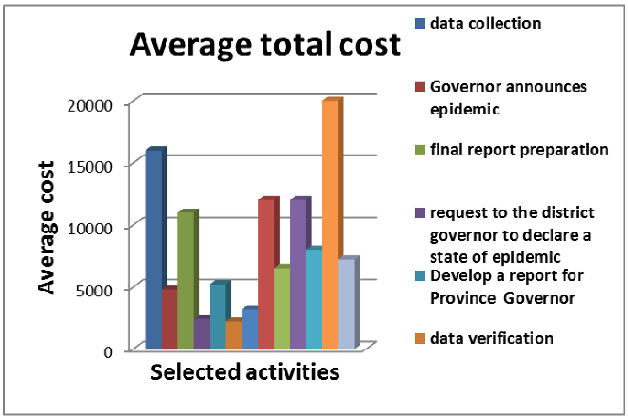

Fig. 17 The average total cost of sanitary inspection activity during the epidemiological investigation

IV. Conclusion

Authors of the study showed how to model the activity of sanitary inspectors during an outbreak of food-borne diseases.

The presented models allow us to determine a number of interesting characteristics of tasks executed by the sanitary inspection.

In order to build the models using the most modern notations and tools we propose to use Forrester's dynamic models and simulation models of business processes.

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