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Simulation Modelling of Information Dissemination Process During Public Notification of Emergency Situations

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***Abstract*—The livelihood of a modern society that has reached a high level of industrial development is subject to a multitude of risks related to environmental problems, the possibility of man-made accidents and other emergency situations. With the aim of protecting the population, the government is carrying out a range of measures that include the task of notifying and informing people of possible threats and about how to behave in various dangerous situations. In doing so, the most important factor is the reduction in notification time and percentage increase in the simultaneous coverage of the population by means of information notification.**

The development of multimedia systems for informing and notifying people of particular events based on modern information and communication technologies is a global trend that reflects the current level of availability of communication means and the perception of information by users across various channels delivering said information. In such conditions, the competent management of information flows and justified selection of channels and engineering means for notification purposes allow one to reach a qualitatively new level of operational efficiency, reliability and targeting.

A pressing task is to develop algorithms and models that make it possible to study trends and patterns within the information dissemination process and conduct simulation experiments to determine the target audience coverage by various means of notification. To this end, this paper offers a simulation model (SM) of the information interaction process in social systems as well as developed algorithmic and computer software that allows for performing computer simulation modelling of the information dissemination process.

Keywords—emergency situation; public notification; communication channels; information dissemination process; simulation modelling

I. Introduction

A high level of industrial development in a modern society, while providing and maintaining a level of comfort in daily life, also bears a variety of well-known negative consequences, such as the danger of man-made accidents, an increased scale of natural disasters, and environmental problems. An excessive concentration of industry in certain regions, increasingly complex manufacturing processes, use of substances that are harmful for human health, and operation of worn-out equipment are all factors that significantly increase both the probability of emergency situations occurring and the socio-economic and material damage that is thereby inflicted.

Concern for people's safety is one of the government's main obligations, and within the range of measures aimed at protecting the population, the tasks of notifying and informing people about threats of emergency situations and how to behave in various dangerous situations are of key importance. The integrated emergency public notification system should ensure the delivery of warning and emergency signals in automated mode.

However, the specifics of an information (post-industrial) society, characterized by rapid development of information communication technologies, and integration of broadcasting technologies, telecommunications and the internet, are constantly establishing new requirements for methods and means of information dissemination. Among such specifics, it is necessary to highlight the following: global urbanization of the population, general dependence upon life support systems, appearance of a considerable number of places of mass accumulation of people, development of transport infrastructure [1].

It is necessary to reduce the time taken to notify people of an emergency situation, ensure a percentage increase in the simultaneous population coverage by information delivery means and, consequently, to develop new approaches and ways of informing the public.

II. The Conditions and Tasks of Notification and Informing the Population of Emergency Situations

Informing the population should be viewed as a complex task that cannot be solved without accounting for the state of the information environment.

The organizational and software/hardware means used to communicate and deliver notification signals to the population should meet the following requirements:

- operational and prompt delivery of information in the sphere of population protection (and for an individual person);
- maximum accuracy and reliability with regard to the information;
- equal information support for the population of cities, regional centers and rural areas;
- record-keeping of the various psychological aspects of understanding and digesting information related to protection in emergency situations, for example, the category of people over the age of 60 needs more intensive and understandable information messages;
- calculation of the rational frequency of information delivery;
- 100% coverage of the population within the emergency zone;
- constraining and counteracting the dissemination of inaccurate and knowingly false information on the events occurred, which can cause people to panic.

The development of multimedia systems for informing and notifying people of particular events is a global trend that reflects the modern availability level of information technologies and the perception of information by users over various channels by which said information is delivered [2].

At present, various information channels are involved in the process of delivering official information to the population: radio and television broadcasting networks, online communities (blogs, social media, electronic cards), mobile systems with a variety of personal devices, special engineering means (outdoor and indoor suspended screens and panels).

For qualitative performance of the tasks related to informing the public, it is necessary to do the following:

- correctly select the channels and means of information provision depending on the aims and content of the information message;
- use the capabilities of information technologies and electronic means of informing the public in order to guarantee that information on the threat of occurrence and on the occurrence of emergency situations and how to behave reaches the population;
- develop mathematical and computer software for forming information flows.

On this basis, a pressing task is to develop algorithms and models that make it possible to study trends and patterns within the information dissemination process and conduct simulation experiments to determine the target audience coverage by various means of notification.

III. Approach to Information Process Modelling

In scientific papers devoted to many application areas of research, the information dissemination processes are studied on the basis of the general theory of networks and are considered "epidemic" by analogy with biological systems (information uptake - as "infecting" a network node) [3-10]. More often than not, attempts to analyze and formalize network information structures are based on analogue differential equations. However, in differential-integral equations it is rather complicated to correlate the coefficients with the characteristics of the system being studied. In addition, the discretization of states of the infected network elements as well as some other features of epidemic processes require using discrete models [11].

Thus, in developing a simulation model of the information dissemination process, a number of limitations have been introduced within the scope of which this model will be accurate and as effective as possible: time is discrete and measured in iterations, the network is limited and connected, modelling is carried out on the grounds of some input statistical data characterizing the network.

IV. Mathematical Model of the Information Dissemination Process

For studying public informing processes, it is proposed to use the following mathematical simulation model.

Let us determine the target audience (the population residing in the emergency zone) as a social system (SS) characterized by the connectivity, communicability and perceptibility of its elements to information activity. Subjective uncertainty is inherent in social systems; therefore, modelling of the processes occurring therein is a problem that is difficult to formalize [12]. To solve this problem, it is expedient to use the fuzzy set theory apparatus [13].

For formalizing subjective data, it is proposed to introduce the "Factor Level" linguistic variable (LV) and specify a term set of its values consisting of three or five elements:

$$\{\text{low; average; high}\}; \tag{1}$$

$$\{\text{strongly\_negative; negative; neutral; positive; strongly\_positive}\}. \tag{2}$$

The information dissemination process (information interaction process - IIP) is believed to occur as follows: Information is introduced into the SS (announced by means of a particular communication channel) at the initial moment in time t=0. Let us call the participants who obtained data from the primary source the initiating set (IS). Further information

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dissemination is provided by interpersonal information exchange. The goal of modelling is to define a fraction of the informed SS members as well as distribute their opinions in terms of set (2) at each step $t=t+1$.

The number K of informed members in the social system at step $t=t+1$ meets the following relation:

$$K_{(t+1)} = K_{(t+1)}\left(L, \bar{b}, q_t, K_{(t)}\right), \quad (3)$$

where L is the volume of the initiating set, $\bar{b}$ is the SS connectivity coefficient (the average number of connections between the interaction participants in the system), q_t is the fraction of participants at step t who are prepared to share the obtained data and disseminate information.

The value of coefficient q_t depends on two factors - the fraction of participants with a high level of sociability and the urgency of information being disseminated at time step t. The sociability level is a permanent property of SS members. The urgency of information usually decreases with time, but in emergency situations that pose a threat to human life and health, the value of this coefficient is predicted to be sufficiently high.

In order to obtain the input data for modelling, it is proposed to use the representative opinion poll method based on sampling. The representative sample (RS) parameters are determined based on statistical data on the general population of the information exchange participants, as well as recommendations from the Federal State Statistics Service for organization of random observations, which allows extrapolating the conclusions obtained to the entire social system.

The characteristics of social systems being large in the number are determined in the form of statistical distributions.

The model parameters are as follows:

- distribution of the number of connections between participants allowing to determine the mean number of contacts per person;
- the fraction of participants prepared to disseminate the information received;
- perceptibility indicators of SS members, to be evaluated according to the values from the linguistic variable term-set (in terms of the fractions of the total number);
- initial distribution of opinions on the topic of information being disseminated (also an estimate in LV fuzzy values, in fractional ratio).

The "perceptibility level" is understood as the individual's tendency to change his/her point of view under the influence of others. The "low perceptibility" value corresponds to an ability to maintain one's opinion under the influence of the information background and the "high perceptibility" value corresponds to a considerable degree of conformability.

For cases of notification on the occurrence or a possible emergency situation, the initial opinions will deliberately be considered "negative" and "strongly negative" or "neutral".

Let us formulate the following rules of information exchange in the SS, which allow formalizing and automating the mathematical calculation:

1) Information is disseminated with a high degree of communicability and with a strongly expressed personal attitude to said information.

2) The opinion of participants with low perceptibility does not change, whereas participants with average and high perceptibility change their opinion when they receive emotionally charged comments.

3) Participants with average perceptibility fall under the influence of external pressure, those with high perceptibility are strongly susceptible to outside influence and can change their opinion drastically.

Let is introduce the following designations:

- $\omega^L, \omega^A, \omega^H$ are the fractions of SS members with low, average and high perceptibility respectively;
- K_t^{++} and ν_t^{++} are the number and fraction of members with a strongly positive attitude to the information being disseminated at the moment in time t;
- K_t^{+} and ν_t^{+} are the number and fraction of members with a positive opinion;
- K_t^{N} and ν_t^{N} are the number and fraction of members with a neutral attitude;
- K_t^{-} and ν_t^{-} are the number and fraction of members with a negative opinion;
- K_t^{--} and ν_t^{--} are the number and fraction of members who have developed a strongly negative attitude at moment t.

Then the number of SS members informed can be determined according to the following formula:

$$K_{t+1} = K_t + q_t \cdot \left(\frac{N-K_t}{N}\right) \cdot \left(K_t^{++} + K_t^{--}\right) \cdot \bar{b}, \quad (4)$$

where N is the total number of people in the target audience, and the coefficient $\frac{N-K_t}{N}$ reflects the fraction of participants that remained uninformed at the previous step.

The number of SS members with a strongly negative attitude to the obtained information can be calculated as follows:

$$K_{t+1}^{--} = K_t^{--} + (K_{t+1} - K_t) \cdot [\nu_0^{--} - \nu_0^{--} \cdot (\omega^A + \omega^H) \cdot \left(\frac{K_t^{++}}{K_t^{++} + K_t^{--}}\right) +$$
$$+\nu_0^{-} \cdot (\omega^A + \omega^H) \cdot \left(\frac{K_t^{--}}{K_t^{++} + K_t^{--}}\right) + \nu_0^{N} \cdot \omega^H \cdot \left(\frac{K_t^{--}}{K_t^{++} + K_t^{--}}\right)] \quad (5)$$

Multipliers $\frac{K_t^{++}}{K_t^{++}+K_t^{--}}$ and $\frac{K_t^{--}}{K_t^{++}+K_t^{--}}$ reflect the fractions of information exchange participants who share strongly expressed positive and negative opinions respectively. According to the formula, it can be seen how participants with average and high perceptibility fall under their influence and change their opinion to a certain side (subtracted or added).

Similarly, the formula for calculating the number of participants with a strongly positive opinion can be determined:

$$K_{t+1}^{++} = K_t^{++} + (K_{t+1} - K_t)\cdot[v_0^{++} - v_0^{++}\cdot(\omega^A+\omega^H)\cdot\left(\frac{K_t^{--}}{K_t^{++}+K_t^{--}}\right)+$$

$$+v_0^{+}\cdot(\omega^A+\omega^H)\cdot\left(\frac{K_t^{++}}{K_t^{++}+K_t^{--}}\right)+v_0^N\cdot\omega^H\cdot\left(\frac{K_t^{++}}{K_t^{++}+K_t^{--}}\right)] \quad (6)$$

V. Automation of the Calculation

As a part of the research, algorithmic and computer software has been developed, which allows performing computer simulation modelling of the information dissemination process in social systems.

The description of the modelling process stages is provided in the form of an IDEF0 decomposition diagram in Fig. 1.

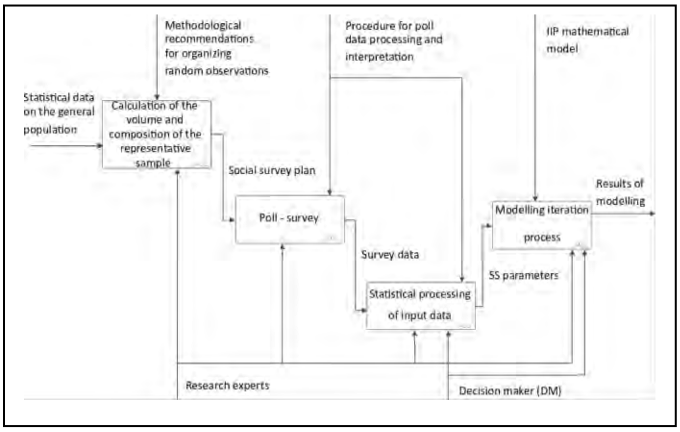

Fig. 1. IDEF0 decomposition diagram of simulation modelling process

At the first preparatory stage, the representative sample parameters are determined. Then, the social system is studied in the form of an opinion poll and the obtained results are subject to processing, to be used as input data for the mathematical model developed. The last stage is the direct iterative modelling with formulation and output of the obtained results.

The software package supporting the IIP modelling technology at all stages has been implemented in the object oriented programming language C#. The simulation modelling software package (SMSP) carries out calculation and output of statistical parameters of the spectra of opinions for varying compositions and volumes of the initiating set of participants via which the information is introduced into the system.

The user is able to conduct simulation experiments for an arbitrary social system to be characterized by any indicators:

- user interface;
- input data preparation module;
- simulation modelling module, implementing the methods for calculating the number of IIP members informed and the distribution of their opinions according to the mathematical model.

Data flows between the modules are implemented in XML format.

The preparatory stage, with calculation of the volume and composition of the representative sample and statistical processing of the results of the poll received, takes place in the form of interactive participation on the part of the operator (researcher). The algorithm of the representative sample calculation is based on the formula taking into account the level of confidence in the results obtained during RS investigation as well as the permissible error limit.

The source of input data for launching the iterative modelling is the XML file of the specified structure with the survey results, as prepared in the first stage, whose content is analyzed by the program in order to determine the parameters of the social system. In addition, the user enters the primary data for characterizing the information dissemination process: the total number of members in the SS, volume of the initiating set and its composition (the fraction of participants with a strongly expressed attitude to information is of significance) as well as the permissible percentage of participants that remained uninformed.

The main stage of simulation modelling after receiving and loading the input data is fully automated. The corresponding algorithm is as follows (Fig. 2).

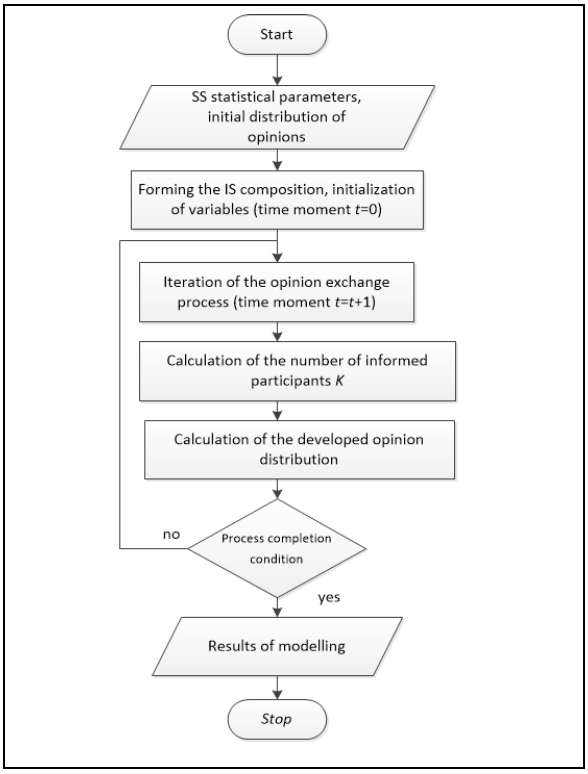

Fig. 2. Simulation modelling algorithm

The completion condition for the information exchange process in the SMSP is reaching the specified threshold in terms of information awareness among participants. The permissible percentage of uninformed participants is to be entered by the user or is set by default by the program as equal to 5% (within the framework of the task related to notification of an emergency situation, it is recommended to set a value close to 0%). For cases when the required level of SS information awareness cannot be reached, it is specified to check the following additional condition: the program will complete the modelling process, if the number of informed participants does not change during 10 consecutive iterations.

For output data, the program will also create an XML file, whose structure makes it possible to store the calculation results at each modelling tact and subsequently display them in tabular form convenient for analysis in Microsoft Excel.

VI. Example Calculation

To identify certain IIP trends, we will provide an example of the social system with 1,437,000 people (the size of the population of the Chechen Republic according to data from 2018). Let us take the following indicators characterizing the SS:

1) Distribution of the number of connections: 80% of participants have between 1 and 5 communication connections; 20% have between 6 and 15 permanent connections with others.

2) Coefficient of perceptibility of outside opinion: for 50% of participants – "Low", for 30% – "Average" and for 20% – "High".

3) Initial distribution of opinions in the SS with respect to the information being disseminated: ν_0^{++}=0, ν_0^{+}=0.01, ν_0^{N}=0.54, ν_0^{-}=0.25, ν_0^{--}=0.2.

4) The fraction of communication participants prepared to disseminate the information received at tact t=0 was determined as q_0=0.55.

The simulation modelling for the social system determined above has been performed in order to study the dynamics of information dissemination for varying volumes of the initiating set (the set of participants that have simultaneously received data directly from an official announcement using a particular means of public notification). As a result, the plots have been derived from the growth in the number of informed participants at each iteration of information exchange.

Fig. 3-5 show graphs reflecting the progress of the information interaction process for cases when the IS volume is equal to 10%, 20% and 30% respectively.

The plots derived have the form of a sigmoid. The information dissemination process is typically characterized by the occurrence of a sharp growth in the number of informed participants starting from a particular moment in time, after which any further transfer of information will practically stop altogether. Thus, full information awareness of the SS, depending on its parameters, may not be reached. A similar vivid presentation of the information interaction process based on the given model allows evaluating the relations between the input parameters and the dynamics of information exchange.

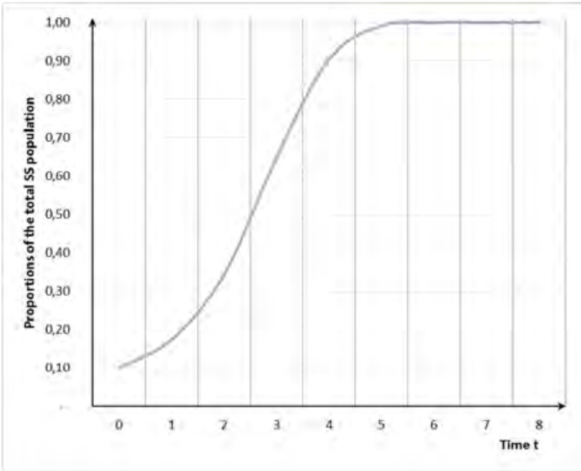

Fig. 3. IIP curve at the initiating set volume of 10%

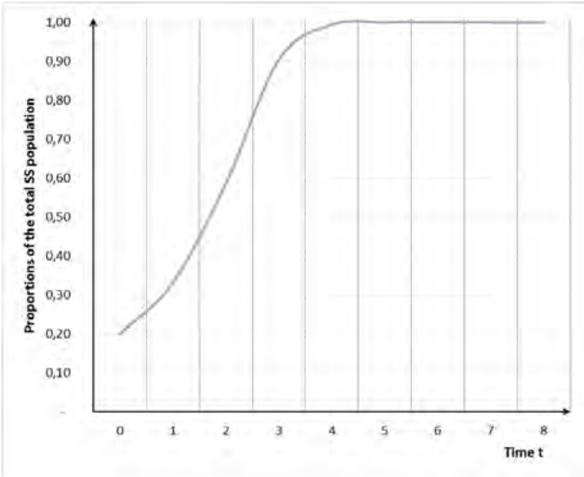

Fig. 4. IIP curve at the initiating set volume of 20%

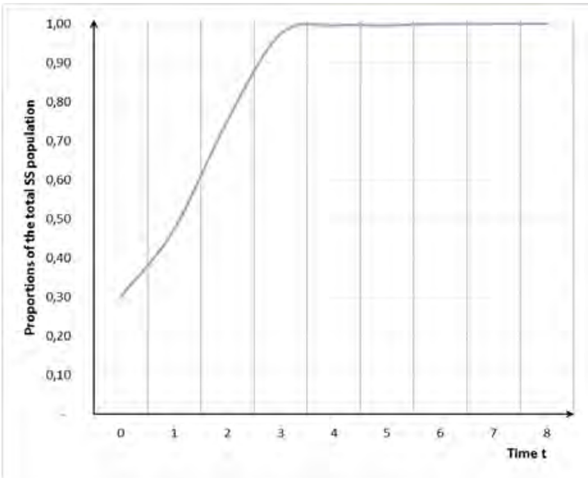

Fig. 5. IIP curve at the initiating set volume of 30%

In the example provided, 100% coverage of the target audience has been obtained. However, it can be seen that the larger the volume of the initiating set, the faster the SS reaches complete information awareness (the stage of sharp growth in the number of informed participants occurs earlier). This approach allows performing an analysis and reasonably selecting the channels and engineering means for notification depending on their availability, as well as making predictions regarding the degree of information delivery to the population.

VII. CONCLUSION

The analysis of the risks of natural and man-made emergency situations at the beginning of the third millennium shows increased probability of their occurrence and damage thereby inflicted. On the other hand, the appearance of new information technologies, development of the technological infrastructure and capabilities of present-day means of communication allow one to adequately respond to these threats regarding the matters of public notification.

Competent management of information flows in such conditions becomes a key factor in ensuring the safety of human life and safekeeping of citizens' material valuables within the scope of emergency situation response measures.

In doing so, the practically oriented approach to the organization of public notification based on use of modern information and communication technologies allows one to reach a qualitatively new level of operational efficiency, reliability and targetability.

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