



**Research Project DN 12/11/December  
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Science Fund at the Ministry of Education and  
Science: “Stochastic and Simulation Models in  
medicine, social sciences and dynamic systems”**

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### Abstract

The project “Stochastics and Simulations Models in the Medicine, Social Sciences and Dynamical Systems” is focused on the stochastics models and their application in the field of medicine, insurance, astrophysics and some simulation models applicable in social sciences and thermohydraulic processes. There are six work packages included in the research. The introduced models had been adapted to real data by three phd students, two post-doctoral students and four Bulgarian scientists which are leaders in the field of mathematical modelling. The participants’ research results are published in eight scientific papers with impact factor and thirty-six papers with impact rang. The results are approbated in more than twenty prestigious international conferences. As a good result of the participation three PhD scientific degrees and two scientific positions have been acquired.

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# 1 Introduction

The introduced stochastic models in the project are from leading fields of medicine such as transplantology, oncology and dentistry. The main purpose of these models in this thematic group is to identify statistically significant predictors (factors) for the prognosis of complications or a fatal outcome in the population of the Bulgarian patients. Some types of the models in this area are models used in the field of the survival analysis and they have a direct relation not only to the field of medicine but also to some insurance and financial theory. Some significant counting distributions with their properties and characteristics with application in risk theory are also given. The main application of these distributions is that they can be used in the construction of a risk model where the counting process follows one of these distributions. A family of Type III Bivariate Inflated-parameter Generalized Power Series Distributions (BIGPSD) is obtained. This family implies compound Generalized power series distributions formed on the base of a bivariate generalized power series distribution where the compounding variables are geometrically distributed. An interesting approach considered during the reporting period is the risk model in discrete time. The counting process used in the discrete model is a compound binomial process with geometric compounding distribution. The process is called the I-Binomial process. It is an analog of the Polya-Aeppli process in discrete time. It is a discrete stationary renewal process for which the inter-arrival times have a modified geometric distribution. A delayed geometric process with exponential inter-arrival times with different parameters between the events is also introduced. The proposed process is a summary of both the Poisson process and the Polya-Aeppli process.

In section “Stochastic models in astrophysics” some statistical distributions which determine the structure and the evolution of the Galaxy are considered. The main achievement here is that a model of star formation which is statistical in nature (from gas molecular clouds to an initial function of the star masses) is successfully created. Another task in this section is considered with the use of some statistical methods for quality assessment of different models for quasiperiodic oscillations of massive gravitational sources such as neutron stars and black holes which are proposed by other teams and made by a comparison of available experimental data in the literature.

The main purpose in section “Social studies” was to develop some simulation mathematical models which consider the influence of the electoral type system of the political and social life in Bulgaria. The connections of the used electoral systems and their influence on the political development in Bulgaria after 1990 are also analyzed.

The modeling and the numerical simulations of the thermohydraulic processes in the nuclear power plants is an area where a plenty of studies exists. In the numerical simulations just one or another of the main elements like active zone, steam generator, etc. of the nuclear power plant can be simulated. The main problems for the created up to now simulation codes are concerned with the fact that they are closed codes and are extremely expensive. Using such types of simulation codes is a difficult task during the training period for the nuclear engineers. So it is difficult to prepare students who study nuclear engineering in the university. In this section some new simplified models of the first circuit of the NPP and its main facilities have been created. The simulation programs have been developed thanks to MATLAB and SCILAB programs.

These programs have an accessible interface through which various processes for visualization and convenience are useful for the students.

The results are approbated in more than twenty prestigious international conferences. As a good result of the participation three PhD scientific degrees and two scientific positions have been acquired.

## **2 Main results achieved in the project**

Shortly the main results achieved in the project in the six separate work packages are as follows:

### **2.1 Work package № 1: “Stochastic models in medicine”**

The main goal of the research given in this package is to identify and to analyze statistically significant factors predictive of some inflammatory processes or mortality in the early period of liver transplantation, neuroblastoma, colorectal carcinogenesis and Paroxysmal Atrial Fibrillation. The statistical methods that are used are logistic regression, analysis of variance, survival analysis and Cox proportional-hazards models. The parameters that had been analyzed as predictors in the constructed logistic models for liver transplantation are levels of bilirubin, sodium, creatinine,



Figure 1: Participation in 46-th International Conference “Applications of Mathematics in Engineering and Economics”, Sozopol

inter international normalized ratio (INR) in blood plasma, post-transplant MELD score (Model for End-Stage Liver Disease) and cold ischemia time after first, second, third, fifth, seventh and tenth postoperative day. The models are constructed on 34 patients’ data which are given from the data base of the University Hospital “Lozenets” - Sofia, Bulgaria. The Survival analysis and Cox proportional-hazards models are used to determine the prognostic significance of Imaging Defined Risk Factors for the time of relapse or death for patiens with neuroblastoma or the prognostic significance of factors for patients with paroxysmal atrial fibrillation.

Two PhD scientific degrees and one scientific position have been acquired in this scientific package.

## **2.2 Work package № 2: “Stochastic processes in insurance risk models”**

The scientific result of the Non-central Polya-Aeppli distribution gives the idea that a counting process in the risk insurance model can be constructed. The constructed process is known as Non-central Polya-Aeppli process. The bivariate analogue of the Non-central Polya-Aeppli distribution is the Bivariate Non-central Polya-Aeppli distribution which is also represented and studied. An interesting result in this package is related with a new stochastic process which is called Polya-Aeppli process of order  $k$  of the second type. It is a compound Poisson process with clumped geometric compounding distribution. This means that in the geometric compounding distribution the mass from  $k + 1$  to infinity is clumped at point  $k$ . The main application of this process is that it can be applied as a counting process in a risk model for which the insurance company is working in unusual environment i.e. environment with major natural disasters, storms, hurricanes, floods, earthquakes and so on. An interesting approach considered during the reporting period is the risk model in discrete time. The counting process used in the discrete model is a compound binomial process with geometric compounding distribution. The process is called the I-Binomial process. It is an analog of the Polya-Aeppli process in discrete time. It is a discrete stationary renewal process for which the inter-arrival times have a modified geometric distribution. A delayed geometric process with exponential inter-arrival times with different parameters between the events is also introduced. The proposed process is a summary of both the Poisson process and the Polya-Aeppli process.

## **2.3 Work package № 3: “Estimation of models for quasi-periodic oscillations of black holes and neutron stars”**

A review of the existing seven models in the literature is given. The scientists in this work package had modeled a data collected for two neutron stars.

## **2.4 Work package № 4: “Starforming models”**

The research of the influence of different physical agents on the gas density distribution function obtained as a solution of the ensemble-averaged Navier-Stokes equation has been studied.

## **2.5 Work package № 5: “Models and numerical simulations of thermohydraulic processes in nuclear power plants”**

A mathematical model which presents the processes in the nuclear reactor's core through the system of Navier-Stokes equations and a mathematical model of a steam generator which is a nonlinear system of ordinary differential equations are obtained. Firstly the mathematical model was developed on Matlab environment for a steam generator and after that the simplified simulator was written from Matlab to SciLAB environment. The simulator developed in this way provides an overview of the steam generator's behavior and its basic mode of operation. The choice of the SciLAB program is not a random one.

On one hand it allows an easy programming of digital procedures, convenient structuring of individual functions of the entire model and provides the opportunity for very good graphics. On the other hand it is an open source product and any student can use it for free. In addition the SciLAB has some ability to develop a graphic interface. The developed simulator can help the learners to understand some basic physical processes, basic operations of complex systems and also to modify or to add equations to the mathematical model of the simulator and thus to extend the model.

## **2.6 Work package № 6: “Models in the social sciences”**

A study of the possible effects of calculating the election results had been conducted. Some codes useful for analysis of the extreme behavior of the proportional methods had been developed. The results obtained during the two project stages had been published in 55 scientific papers where eight papers are with impact factor and thirty-six papers are with impact rang. The project participants had reported the scientific results at over 20 scientific conferences in the country and abroad. During the project period three participants defended PhD scientific degree and two scientific positions from two post-doctoral students had been acquired. A productive cooperation among over thirty Bulgarian and foreign scientists had been made.