Modelling of Analytical Function in the Financial Knowledge Discovery Model

Vladimir SIMOVIC, Zlatko GOLUBIC, Savo VOJNOVIC
University of Zagreb, Police College
Avenija Gojka Suska 1
HR–10000 Zagreb, The Republic of Croatia
e-mail: vladimir.simovic@zg.tel.hr

Abstract. Objective of this work is to explain the modelling concept of analytical function in the financial knowledge discovery model. This new simulation model of analytical function is developed for a financial knowledge discovery process that is used for the Corporate Criminal Intelligence Analysis (CCIA, in short). Model was developed for the CCIA work of the whole analytical part of the Financial police of the Republic of Croatia. The benefit of this new simulation model of analytical function is in simple method (based mainly on statistical simulations) of measuring analytical capacity and capability of analysis, which is now in usage in the financial field and field of law. The analytical function of the CCIA was prepared for investigations of financial criminal incidents, financial criminal offenders or victims and for financial crime control methods, etc. An application of this simulation model increases the group effectiveness, efficiency, and quality of the operational and strategic financial investigative operations that are in usage during the whole financial knowledge discovery process.

Key words: applied simulation model, knowledge discovery process, corporate criminal, intelligence analysis.

1. Introduction

About two years old changes of the Croatian Criminal and the Criminal Processing Law, and new organisational and financial aspects in Financial and Criminal police practice was opportunity for adoption of an original analytical concept of the Corporate Criminal Intelligence Analysis (CCIA) and challenge for modelling of analytical function in the developed financial knowledge discovery model (Simovic, Golubic, Skugor, 1999; Simovic, Radic, Zrinusic, 1998; Simovic, Simundic, Radic, 1998; Simovic, Zrinusic, 1999; Simovic, Zrinusic, Skugor, 1999). Fact is that "raster" analysis of all electronic databases connected with concrete offender, or with specific criminal group and their criminal acts, for period of six or maximum nine months (proposition from article 183 of the Criminal Processing Law of the Republic of Croatia) can be well done only with prepared and original analytical concept. Foundation for modern criminal combating practice is concept of corporate analytical work that is done with financial analysts and scientific police units (for combating with all kinds of economic (especially financial) crimes,

organised crimes, and some other serious crimes). Operations research (OR) and information based financial modelling theory proposes broadly usage of tactical and strategic CCIA, which is financial founded (and dealing with interesting or crime related information's and data). Critical to the usefulness of financial transaction analysis (in the developed financial knowledge discovery model) is valid representation of the data in a OR form that facilitates and enhances corporate analysis but does not preclude further interpretation or alternate or expansion as a result of additional information. In this paper we analyse the problem of OR based modelling of analytical function in the CCIA process connected with developed financial knowledge discovery model. Our OR study overlapping phases are (see also "Overview of the OR Modelling Approach", p. 8 in (Fong, Huang, 1997)):

(I) Main problem definition and relevant data gathering; (II) OR or a mathematically based model formulation (as satisfying problem representation); (III) Computer-based procedures development with satisfying programming problem solutions derivations; (IV) Model testing and refinement process; (V) Preparation for the future applications of the developed model; (VI) Implementation and maintenance process.

2. Introduction to Approach Used

In this section of our OR main study ("Developing The Whole Financial Knowledge Discovery Model") the main problem was how to choose the best (good, precise, fast and easy) prediction model of the established analytical function in the financial knowledge discovery model, which is used during the whole CCIA process.

2.1. *Simulation Modelling of the Basic Parameters of the Used Analytical System*

In relation to the proposed classification of the simulation models (see p. 14 in (Ziljak, 1982)) here we are taking about OR study that is mainly dealing with abstract, dynamic, discrete, and stochastic models with numerical and analytical end solutions, which are primarily accomplished with a lot of discrete simulations and with recording data on developed model (for more details see pp. 16–21 in (Ziljak, 1982)). Usually stochastic variable can be introduced in simulation model (for testing and analysis) because of: incomplete knowledge about researched system (when deterministic approach must be excluded), better model economics (caused by taking the stochastic variable when the knowledge about system is complete and when stochastic approximation is possible), and better operationally usage of the developed model (for more details about: stochastic variables, method "Monte Carlo", simulation experiments and simulation languages see pp. 23–107 in (Ziljak, 1982)). In this paper we are using simplified explanation of the analytical function and basically complex multi-channel supplying system (for analytical information's). For better clarity suppose that in all financial investigations we are analytically dealing mainly with financial based information's and data. Also, we are dealing with a lot of "analytical information's", which are coming from legal sources and in some order that is proposed from well known "supplying theory" or "queuing theory" (Ziljak, 1982).

2.2. *OR Model of the Modern Analytical Investigation Function*

Both models (model of CAI – classical analytical investigation, and model of MAI – modern analytical investigation) we are researching have two basic analytical sub-systems: service receivers (analytical function clients) and service suppliers (analytical function servers). Simplified, analytical service receivers are coming in channels (with and without queues) with all kind of "analytical information's" (maybe) interesting for financial investigations (and especially for financial analysis function). If there are free analytical service suppliers then analytical service will be done in that moment. But, if there is no free analytical service supplier's, service receivers are waiting for the service in queues. After the analytical service request was accomplished, analytical service receivers (fully analytical prepared information's) are living the analytical system, or coming to the end of it (or to the specific destination point). Analytical supplying system can be simple or complex, open or closed, one or multi-channel, and also with and without priorities (see pp. 108–175 in (Ziljak, 1982)). Simplified, CAI is simple multi-channel analytical supplying system, but MAI is complex multi-channel analytical supplying system with priorities, and it is always-bigger system than CAI. MAI has minimally two (see 4th and 5th analytical server, on Fig. 1) or n analytical servers plus then CAI, and it has backward feedbacks sub-system (well known as $\ll 4 \times 4 \times 2 \gg$ evaluation sub-system) (..., 1998). MAI (which is broadly used in the CCIA) is functionally complex, have multi-channel structure, backward feedbacks, tails with queuing and analytical information's supplying sub-system with priorities. That is reason that we are here researching rather simplified (without backward feedbacks sub-system), but complex multi-channel analytical supplying system with priorities (see Fig. 1).

Intelligence has added value as the result of OR based analysing and interpretation. It must be clear that the serious crime combating practice is basically done with various experts, analysts and scientific units for combating with all kinds of relatively complex crime and that combating resources are finite. The operational crime combating practice with finite number of specialists and usually lot of cases during the same time period produce a need for parallel and network working. The whole CCIA process has almost clear heuristics, because intelligence is the resulting product from various systematically connected OR based processes, like: estimation, collection, evaluation, collation, integration, analysing and interpretation of data and information, development of hypotheses, dissemination of information, intelligence acting, co-ordination and automation are (Simovic, Golubic, Skugor, 1999; Simovic, Radic, Zrinusic, 1998; Simovic, Simundic, Radic, 1998; Simovic, Zrinusic, 1999; Simovic, Zrinusic, Skugor, 1999).

2.3. *OR and Mathematically Based Model Formulation*

The following extension of standard terminology and notation is used:

state of analytical system – number of a analytical data (or information) in queueing
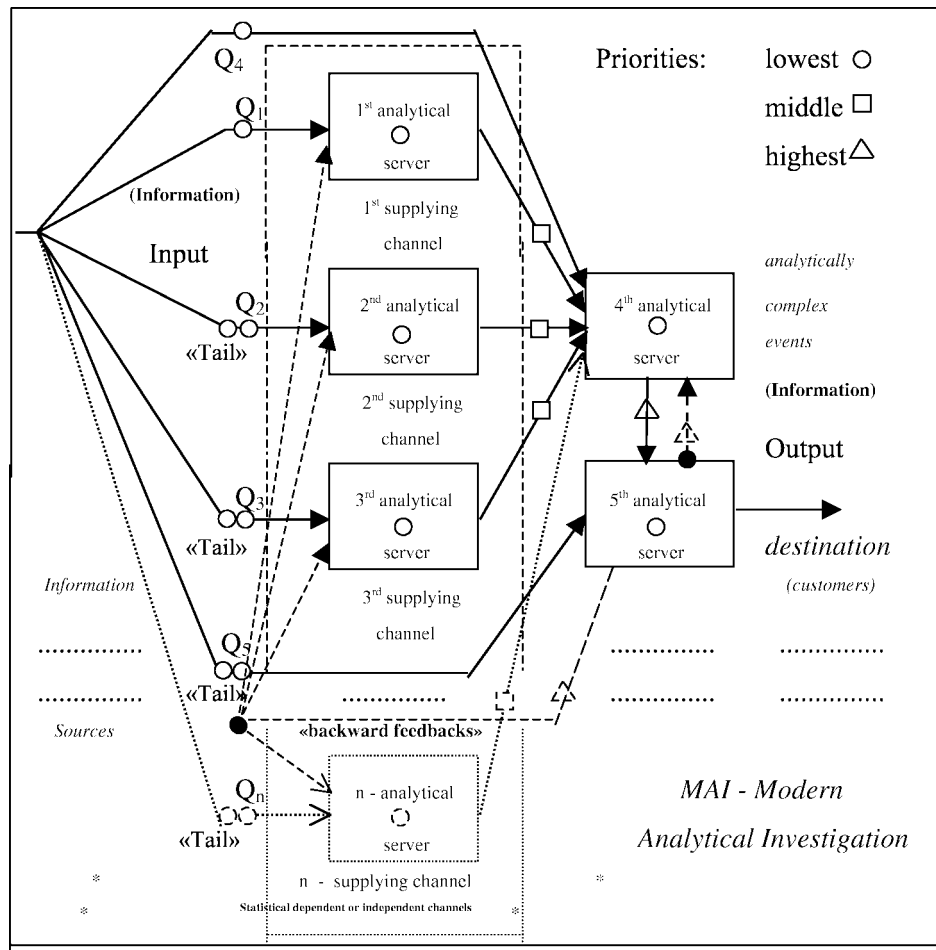   system;

Fig. 1. Complex multi-channel analytical supplying system with priorities.

analytical queue length – number of a analytical data (or information) waiting for service
(state of analytical system minus number of a analytical data being analytically
served);

$N(t)$ – number of a analytical data (or information) in queueing system at time t (t);

$P_n(t)$ – probability of exactly n analytical data (or information) in queueing system at
time t, given number at time 0;

s – number of analytical servers (parallel analytical service channels) in queueing;

λ_n – mean arrival rate (expected number of arrivals per unit time) of new analytical data
(or information) when n data (or information) are in queueing system;

μ_n – mean analytical service rate for overall queueing system (expected number of data
(or information) completing analytical service per unit time) when n data (or in-
formation) are in queueing system (Note: that is combined rate at which all busy
analytical servers (serving data) achieve analytical service completions).

λ (constant) – when the mean arrival rate λ_n is a constant for all n;

μ (constant) – when the mean analytical service rate per busy analytical server is a constant for all $n \geqslant 1$ (Note: in this case, $\mu_n = s\mu$ when $n \geqslant s$, or when all analytical servers s are busy);

$1/\lambda$ – expected interarrival time;

$1/\mu$ – expected analytical service time;

ρ – the utilization factor ($\rho = \lambda/s\mu$) for the analytical service facility, or the expected fraction of time the individual analytical servers are busy;

steady-state condition of analytical system – specific state of analytical system that is reached after sufficient time has elapsed (after transient condition of analytical system is finished), and when analytical system is essentially independent of the initial system state and elapsed time (where the probability distribution of the state of the analytical system remains the same);

P_n – probability of exactly n potential analytical data (or information) in analytical queueing system;

L – expected number of analytical data (or information) in analytical queueing system;

L_n – expected analytical queue length (excludes analytical data or information being served);

W – waiting time in analytical queueing system (includes analytical service time) for each individual analytical data or information;

W_k – steady-state or total expected waiting time in the whole analytical system (including analytical service time, or analytical supplying time), where $W = E(W)$ and W_k is for a member of priority class k, which is $k = 1, 2, \ldots, N$;

W_q – waiting time in queue (excludes analytical service time) for each individual analytical data or information, where $W_q = E(W_q)$.

During the research preserved we are not using the elementary model **M/M/1** of the "queuing theory", which is in fact one-channel (one server) analytical supplying system model with exponential distribution (Markovian) of inter-arrival times (of analytical information) and of (analytical supplying) service times. We are using the specific **M/M/s** model (for more details see pp. 628–755 in (Fong, Huang, 1997)), which assumes:

- that all inter-arrival times are independently and identically distributed according to an exponential distribution (our input process is Poisson);
- that all analytical service times are independently and identically distributed according to another exponential distribution (our analytical service process is Poisson);
- that the number of servers is s (any positive integer), but in the Croatian CCIA practice and related analytical function they vary from minimum 1 to maximum 7.

With the equal distribution of analytical supplying time, with expected service time about $1/\mu$ (μ_n is mean service rate for overall system, or expected number of clients (or customers) completing analytical service per unit time), and with exponentially distributed inter-arrival time of analytical information at expected average rate of $1/\lambda$ (λ_n is mean arrival rate, or expected number of arrivals per unit time), that is the most simplified type of Markovian analytical system with supposed infinite analytical capacity

($Y = \infty$), and with priorities in queue discipline (or without supposed FIFO (First-In/come/-First-Out/served/) queue discipline). We are researching the analytical cases in which there are no possibilities for any analytical closeness of multi-channels model of analytical supplying function, or when utilisation factor for the analytical service facility is $\rho_s < 1 \Leftrightarrow \lambda < s\mu$ (because $\rho_s = \lambda/s\mu$). For better clarity about priorities concept, now we are talking about elementary model of analytical supplying system ***M/M/1***, which has stationary state represented with these relations (see pp. 122–123 in (Ziljak, 1982)):

$$p(n) = \rho^n(1 - \rho);$$
$$\rho = \lambda/\mu < 1;$$
$$p(0) = (1 - \rho);$$
$$L = \rho/(1 - \rho) = \lambda/(\mu - \lambda);$$
$$L_q = \rho^2/(1 - \rho) = \lambda^2/\left[\mu(\mu - \lambda)\right];$$
$$W_q(t) = \begin{cases} 1 - \rho & \text{for } t = 0, \\ 1 - \rho \cdot e^{-\mu(1-\rho)t} & \text{for } t > 0; \end{cases}$$
$$W_q = \lambda/\left[\mu(\mu - \lambda)\right];$$
$$W = 1/(\mu - \lambda); \quad T_{\text{occupied}} = 1/(\mu - \lambda).$$

With introducing only two relative priority classes of analytical supplying function in the same ***M/M/1*** model, we have analytical information with higher priority of relative analytical supplying order, which have mean arrival rate λ_1 (i priority class is equal 1), and analytical information with lower priority of relative analytical supplying order which have mean arrival rate λ_2 (i priority class is equal 2). Parameter of their corporate (coupled) input exponential distribution is λ, and it is their arithmetic sum ($\lambda = \lambda_1 + \lambda_2$). Analytical supplying function is the same for both type of analytical information, and have mean service rate μ. Basic results for average measures of success (in stationary state condition) can be represented with these relations (see pp. 126–128 in (Ziljak, 1982)):

$$L^{(1)} = (\lambda_1/\mu)(1 + \rho - \lambda_1/\mu)/(1 - \lambda_1/\mu);$$
$$L_q^{(1)} = (\rho\lambda_1/\mu)/(1 - \lambda_1/\mu);$$
$$W_q^{(1)} = \lambda/\left[\mu(\mu - \lambda_1)\right];$$
$$L^{(2)} = \left[(\lambda_2/\mu)(1 - \lambda_1/\mu + \rho\lambda_1/\mu)\right]/\left[(1 - \rho)(1 - \lambda_1/\mu)\right];$$
$$L_q^{(2)} = (\rho\lambda_2/\mu)/\left[(1 - \rho)(1 - \lambda_1/\mu)\right];$$
$$W_q^{(2)} = \lambda/\left[(\mu - \lambda)(\mu - \lambda_1)\right];$$
$$p(n) = \rho^n(1 - \rho) \text{ for } n > 0;$$
$$p(0) = (1 - \rho);$$
$$\rho = \lambda/\mu < 1;$$
$$L = L^{(1)} + L^{(2)};$$
$$L_q = L_q^{(1)} + L_q^{(2)};$$

$$W_q = (\lambda_1/\lambda)W_q^{(1)} + (\lambda_2/\lambda)W_q^{(2)};$$
$$W_q^{(2)}/W_q^{(1)} = \mu/(\mu - \lambda).$$

But in multi-channels model ***M/M/s*** we have priority sub-system with N (where $N = 1, 2, \ldots, k$) relative priorities classes, and where W_k is steady-state or total expected waiting time in the whole analytical system (including service time, or analytical supplying time). In stationary model situations W_k can be explained in relation (see pp. 706–707 in (Fong, Huang, 1997)):

$$W_k = \frac{1}{AB_{k-1}B_k} + \frac{1}{\mu},$$

for a member of priority class k, which is $k = 1, 2, \ldots, N$, where:

$$A = s!\frac{s\mu - \lambda}{r^s}\sum_{j=0}^{s-1}\frac{r^j}{j!} + s\mu,$$

$$B_0 = 1,$$

$$B_k = 1 - \frac{\sum_{i=1}^{k}\lambda_i}{s\mu}, \quad \text{for } k = 1, 2, \ldots, N,$$

s – number of analytical servers,

μ – mean service rate per busy server,

λ_1 – mean arrival rate for priority class i, for $i = 1, 2, \ldots, N$,

$$\lambda_1 = \sum_{i=1}^{N}\lambda_i,$$

$$r = \lambda/\mu \quad (\text{What assume that}: \sum_{i=1}^{k}\lambda_i < s\mu).$$

The steady state expected number of members of priority class k in the queuing system (including those being analytically served) is L_k, and it can be explained in relation:

$$L_k = \lambda_k W_k, \quad \text{for } k = 1, 2, \ldots, N.$$

The expected waiting time in the queue (excluding service time) for priority class k is $W_q(k)$, and it can be explained in relation:

$$W_q(k) = W_k - 1/\mu.$$

The corresponding expected queue length ($\ll$tail length$\gg$) is $L_q(k)$, and it can be explained in relation:

$$L_q(k) = \lambda_k W_q(k).$$

2.4. *Computer-Based Simulation Modelling Design, Model Testing and Refinement Process*

We prepared our computer-based simulation modelling design mainly with ≪MathProg≫ and ≪ProbMod≫, which are modular developed McGraw-Hill programs for various simulation solutions (see pp. 947–950 and accompanied disks in (Fong, Huang, 1997)).

That design was controlled with modular simulation programs solutions designed in Fortran'77, Fortran'90 and Lahey language (and supported with C++ source code for: DOS, QuickWin, Windows'95, Windows'98, Xwindow'X11 and NT Windows) taken from Springer-Verlag Compact Disk (see pp. 595–608 and accompanied CD in (Brandt, 1999)).

We have completely finished 62 simulation-modelling experiments with different types of *M/M/s* multi-channel analytical models. Also, we were researching the possibility of rationally dimensioning and organisation of analytical function without stopping in stationary state of the developed analytical model. We were researching behaviour of developed *M/M/s* model type in relation with various intensity of analytical traffic (see Tables 1, 2 and 3). We were changing exploiting variables of analytical system ($\rho_s = \lambda/s\mu$), in all combinations for values: $\lambda = \{2, 3, 4\}$, $\mu = \{4, 5, 6\}$, and for models: $M/M/1$, $M/M/2$, $M/M/3$, $M/M/4$, $M/M/5$, $M/M/6$ and $M/M/7$ (number of analytical servers varies from 1 to 7, or $s = \{1, 2, 3, 4, 5, 6, 7\}$).

Simulation modelling results were good (see next tables and figures).

According to Tables 1, 2 and 3 we can make uniform graphical representations on behaviour of developed *M/M/s* model types in relation with various intensity of analytical traffic (see Figs. 2, 3, 4, and 5).

2.5. *The Future Applications and Implementation*

Uniform graphical representation can be used as a part of simple method for measuring analytical capacity and capability of analysis (which can be used in the financial field and field of law). How?

Table 1

Different exploiting of analytical system (ρ_s), for various simulation models of *M/M/s* type, and for the same arrival rate for analytical information $\lambda = \{4\}$

$\rho_s = \lambda/(s \cdot \mu)$	$\mu = 4$	$\mu = 5$	$\mu = 6$
$s = 1$	–	0.800	0.667
$s = 2$	0.500	0.400	0.333
$s = 3$	0.333	0.267	0.222
$s = 4$	0.250	0.200	**0.167**
$s = 5$	0.200	0.160	0.133
$s = 6$	**0.167**	0.133	0.111
$s = 7$	0.143	0.114	0.095

Table 2

Different exploiting of analytical system (ρ_s), for various simulation models of **M/M/s** type, and for the same arrival rate for analytical information $\lambda = \{3\}$

$\rho_s = \lambda/(s \cdot \mu)$	$\mu = 4$	$\mu = 5$	$\mu = 6$
$s = 1$	0.750	0.600	0.500
$s = 2$	0.375	0.300	0.250
$s = 3$	0.250	0.200	0.167
$s = 4$	0.188	0.150	**0.125**
$s = 5$	0.150	0.120	0.100
$s = 6$	**0.125**	0.100	0.083
$s = 7$	0.107	0.086	0.071

Table 3

Different exploiting of analytical system (ρ_s), for various simulation models of **M/M/s** type, and for the same arrival rate for analytical information $\lambda = \{2\}$

$\rho_s = \lambda/(s \cdot \mu)$	$\mu = 4$	$\mu = 5$	$\mu = 6$
$s = 1$	0.500	0.400	0.333
$s = 2$	0.250	0.200	0.167
$s = 3$	0.167	0.133	0.111
$s = 4$	0.125	0.100	**0.083**
$s = 5$	0.100	0.080	0.067
$s = 6$	**0.083**	0.067	0.056
$s = 7$	0.071	0.057	0.048

We can now easily find specific exploitation level (for example 30%, or $\rho = 0.3$) from Fig. 4, and for specific number of analytical servers (for example 4, or $s = 4$) determine which is maximum intensity of analytical traffic (for this example it is in range from $4/5$ to $4/4$, or $\lambda/\mu = [4/5, 4/4]$; see Fig. 5).

3. Conclusion

One of future applications of the developed simulation model we can see in Fig. 4. The application of analytical queueing theory concept is very broad. For example, uniform graphical representation can be used as a part of simple method for measuring analytical capacity and capability of analysis (which can be used in the financial field). How?

Now, from Tables 1, 2, 3 and from Fig. 5, we can easily find for specific exploitation level (for example it is 30%, or $\rho = 0.3$), and for specific number of analytical servers (for example $s = 3$) what is maximum intensity of analytical traffic (for this example it is in range from $4/5$ to $4/4$, or $\lambda/\mu = [4/5, 4/4]$). Or in opposite direction example, we can find for specified maximum intensity of analytical traffic (say it is in interval
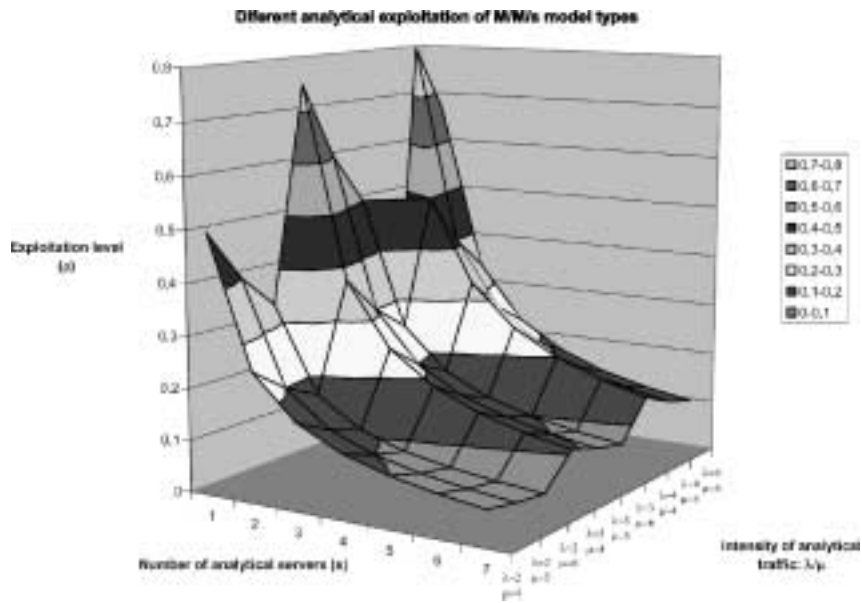
Different analytical exploitation of M/M/s model types

Fig. 2. Graphical representation of all simulation modelling results (experimental data from Tables 1, 2 and 3).

Uniform exploration of different configuration of the M/M/s model type
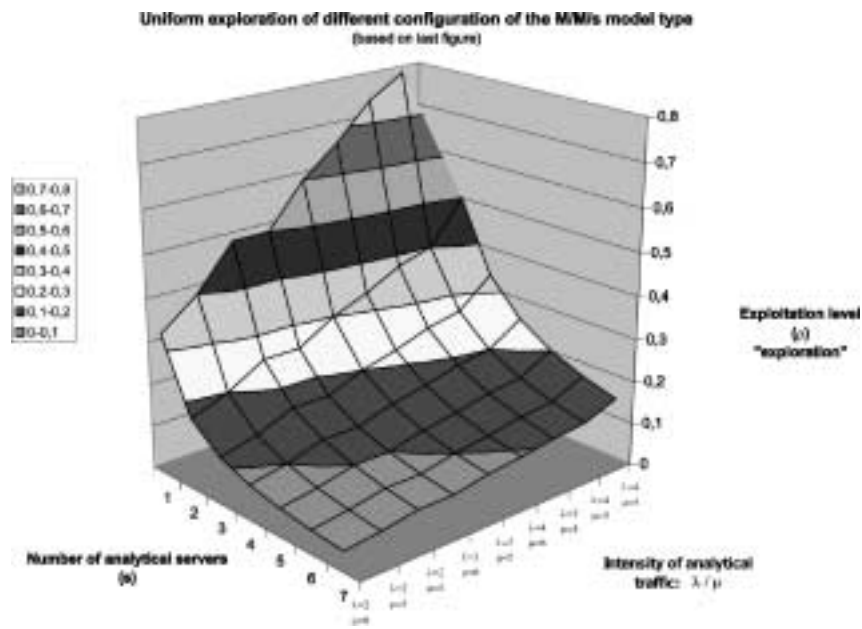(based on last figure)

Fig. 3. Uniform graphical representation as result of uniform analytical loading and refinement process (all data from Tables 1, 2 and 3).
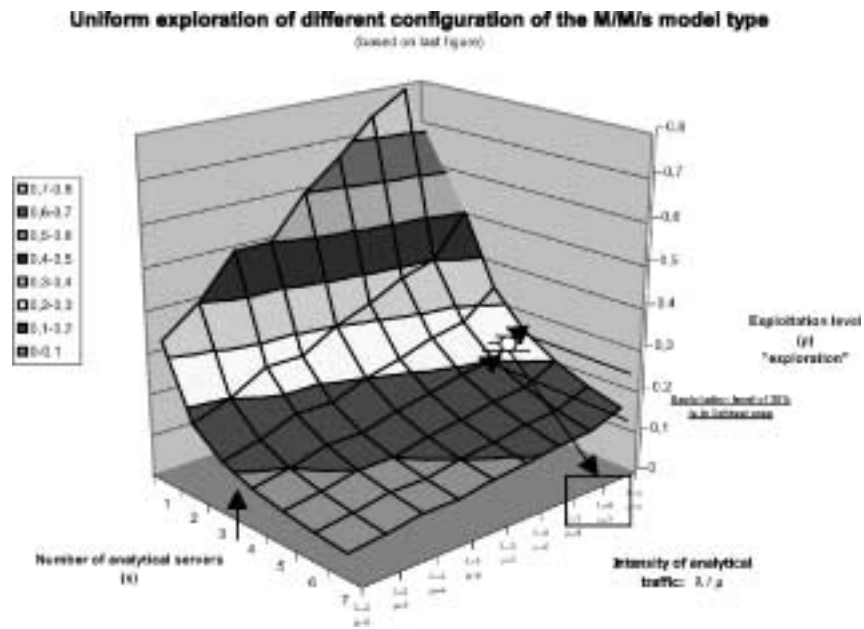
Fig. 4. Graphical representation of usage example ($\rho = 30\%$ or $\rho = 0.3$; $s = 4$).
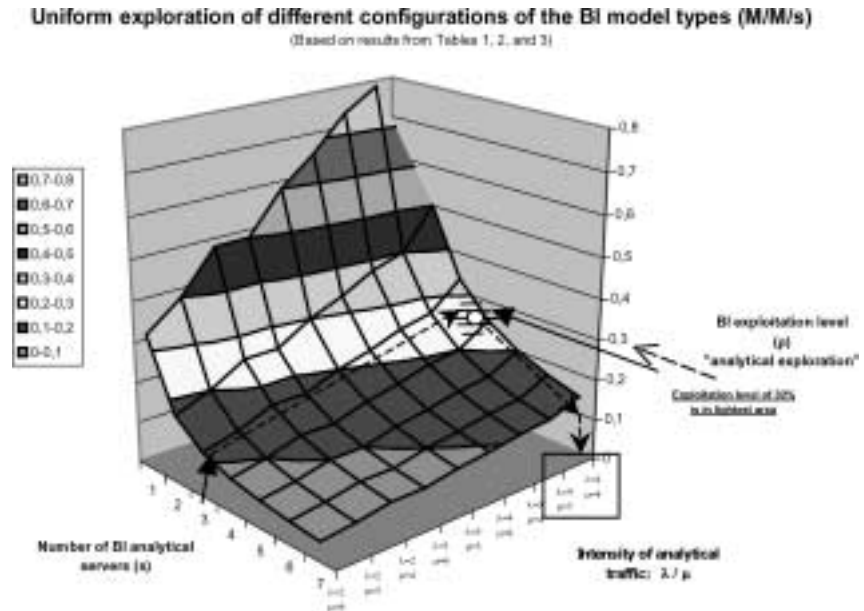

Fig. 5. Graphical representation of usage example ($\rho = 0.3$ and $s = 3$).

$\lambda/\mu = [4/5, 4/4]$), and for specific number of analytical servers (say it is s = 4) what is the specific exploitation level (it can be from 20% up to 25%).

This simulation model of analytical function is developed for a financial knowledge discovery process that is used for the CCIA. Model was developed for the CCIA work of the whole analytical part of the Financial police of the Republic of Croatia, and now we can find real input data and see real analytical distributions, what means that we can experiment on real model and compare results. This can radically change quality of the strategic and tactical CCIA processes. Processes can be analytically measured; they can be also much faster and for sure better (in future). Conclusion is also that simulation software solutions must obey trends of OR modelling in informational and financial aspects of the analytical function of the CCIA involved. Important is to use the appropriate software tools in dealing with the financial type of criminal incident, or the financial type of criminals, or the methods employed to control any type of crime (especially financial type of crime).

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V. Simovic received Ph.D. degree from the Zagreb Faculty of Law, Zagreb, Croatia, 2000, in scientific field of informatics. He is an associated professor at the University of Zagreb, fully time at the Police College in Zagreb (Croatia) and partly time at the College for Business and Management in Zapresic (Croatia). He is also senior researcher and project leader for consulting services in the name of the Official Consultant for the Croatian Custom Directorate (at the Ministry of Finance of the Republic of Croatia) on the relation to the World Bank and Croatian Government Contract. His research interests include: the classical and intelligent information systems development problems; OR aspects (informational and financial, operative and strategic) of various (criminal, competitive or business) intelligence models; and modeling aspects in field of: forensic computing, digital-payment, etc. Also, his research interest includes various approaches to the classical and modern statistical systems, especially in field of stochastic simulations, simulation modeling and analysis, as well statistical and informational (even artificial intelligence) software tools processes. He published more than 50 papers and 3 books about information science and about various OR modelling aspects (information and financial modelling aspects). He was actively involved in more than 8 scientific and business projects (leading, projecting or consulting – in field of information science). He was also one of two authors of the intelligent information system of the Croatian Anti Money Laundering Department at the Ministry of Finance of the Republic of Croatia, and official consultant of the Chief Inspector of the Croatian Financial Police for development of the Croatian Financial Police integral information system at the Ministry of Finance of the Republic of Croatia. Also, he was one of co-authors on three projects of the Ministry of Science and Technology of the Republic of Croatia. Now he is senior researcher (in scientific field of informatics) at the one scientific project of the Ministry of Science and Technology of the Republic of Croatia.

Z. Golubic received Master degree from the Zagreb Faculty of Politics Sciences, Zagreb, Croatia, 1990, in scientific field of informatics. He is a higher scientific assistant at the University of Zagreb, at the Police College in Zagreb (Croatia). His research interests include: various OR and information science models (operative and strategic), as well relations between information security and informational or modern business development. Also, his research interest includes various approaches to the classical and modern information security systems, especially in field of protection modeling and security analysis. He published more than 10 papers about various scientific aspects of modeling in informatics and information security. He was actively involved in some scientific projects (in field of informatics). Now he is finishing his doctoral thesis about various aspects and relations between information security and modern business for the Croatian companies. He is scientific assistant researcher (in scientific field of informatics) at the one scientific project of the Ministry of Science and Technology of the Republic of Croatia.

S. Vojnovic received Ph.D. degree from the Zagreb Faculty of Economics, Zagreb, Croatia, 1985, in scientific field of Economics. He is a full professor at the University of Zagreb, fully time at the Police College in Zagreb (Croatia) and partly time at the Faculty of Economics in Zagreb (Croatia). His research interests include: various OR and economy science models, as well relations between economical and technical development (and macro economical models). Also, his research interest includes various approaches to the classical and modern economical systems, especially in field of mathematical modeling and economical analysis. He published more than 30 papers and 3 books about various scientific aspects of modeling in economy. He was actively involved in some scientific projects (in field of economy science). Now he is senior researcher (in scientific field of Economics) at the one scientific project of the Ministry of Science and Technology of the Republic of Croatia.

Analitinių funkcijų modeliavimas finansinių žinių paieškos modeliuose

Vladimir SIMOVIC, Zlatko GOLUBIC, Savo VOINOVIC

Šio darbo tikslas yra paaiškinti finansinių žinių paieškos modelių analitinių funkcijų modeliavimą. Šis naujas analitinių funkcijų modeliavimo metodas yra skirtas finansinių duomenų paieškos korporuotai kriminalinei analizei (Corporate Criminal Intelligence Analysis – CCIA, angl.). Modelis buvo sudarytas CCIA veiklai kaip Kroatijos respublikos Finansų policijos analitinė dalis. Šio metodo privalumai yra matuojamų analitinių pajėgumų paprastumas ir galimybė pasinaudoti dabar atliekama analize finansų ir įstatymų srityje. Analitinės CCIA funkcijos buvo paruoštos tirti finansiniams kriminaliniams incidentams, finansinių nusikaltimų kaltininkams bei aukoms ir finansinių nusikaltimų kontrolės būdams, ir pan. Šio metodo panaudojimas didina finansinių tyrimo operacijų, dažniausiai naudojamų finansinių žinių paieškai, efektyvumą bei kokybę.