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**Abstract**

The paper reviews the concepts of system dynamics and its applications to the simulation modeling of financial institutions daily activity. While widely applicable, the approach is of a particular interest in transitional and developing economies. The hybrid method of banking business processes re-engineering based on a combination of system dynamics, queuing theory and ordinary differential equations (Kolmogorov equations) is introduced. By the way of method illustration, we consider the promotion of a set of banking products among some categories of clients.

## 1. Introduction: the brief review of  present state

The presence of material, financial and social components in the structure of economical systems and processes requires an application of  different tools in accordance with a level of simulation model. As the practice demonstrates, the manufacturing and technological models (frequently considered as queuing systems) can be adequately modelled by means of discrete-eventual simulation systems  such as GPSS.  The financial models fit well into the framework of system dynamics. The

multi-agent approach can be useful to the simulation modeling of labour relations. Moreover, for a long time, researchers had differing views on economical processes simulation models creation and used miscellaneous approaches to the development of the related software.

Although there are many computer simulation methods actively used today, the paper particularly focuses on system dynamics. The foundation of this theory was laid in the 1950s by J. Forrester [4]. System dynamics was offered as a tool for the research of the behavior of industrial systems by means of detecting information feedbacks. The purpose of this procedure is to study the interaction of the structure, amplifications in business policies, and delays in decision making and to evaluate the influence of these factors on the efficiency of a firm and on its business operations. According to Forrester [5, p. 5]: "System dynamics combines the theory, methods, and philosophy needed to analyze the behavior of systems in not only management, but also in environmental change, politics, economic behavior, medicine, engineering, and other fields".

This flexible approach to organisational business processes description is also a powerful practical tool for an enterprise architect. Currently, the differential equations which are the mathematical foundation of system dynamics are not included in everyday operations of many financial institutions. Today this approach is particularly relevant in transitional and developing economies as they require ever more powerful tools for analysis and forecasting in turbulent environment.

The concept of system dynamics implies a maximum model abstraction level by describing the structure of a system and system's behaviour as a set of interacting positive and negative feedbacks and delays. Relying on processes that are continuous in time, the system dynamics apparatus allows a researcher to represent a simulation model in the form of a system of differential equations (mapping real economical processes to inflows and outflows between funds). The methods of system dynamics are implemented in a significant number of software tools (DYNAMO, Vensim, PowerSim, iThink, Stella, AnyLogic™ etc.).

The long-term international case record of this technique has clearly demonstrated its advantages compared to competitive methodologies. First of all, system dynamics models are essentially more effective for detecting and understanding of behavior patterns compared to conventional economic-mathematical models. Secondly, they easily allow for corrections in the form of Forrester's delays and nonlinearities, and the latter provide for a more precise description of a state of a modelled process (in particular, it is extremely important for the research of banking institutions and their subsystems). Finally, the approach of system dynamics allows a researcher to estimate even low couplings (when some factors cannot be credibly measured) and to introduce these factors in the model in a way that makes it possible to extend the number of predicted scenarios of behavior of a studied object (by a principle "What will happen, if?...").

It is not hard to explain the attention of a large number of scientists and professionals to the problems of applying system dynamics to economics; operating control, forecasting, and strategic planning all require regular simulation both of regular activity and of critical situations with the goals of the best preparedness to events and the best adaption to the environment.

## 2. Formulation

The activity of a bank institution consists in the transformation of a flow of the attracted capitals in a flow of bank transactions involving financial assets. According to this general plan, most accessible and straightforward simulation models of banks are developed. It follows that the system dynamics model of a bank should reflect both positive and negative feedbacks being most representative for the financial activity. These feedbacks are linking the following Forrester's stocks: {*deposits*; *interbanking receipts*; *other liabilities*} and {*loans*; *investment*; *other assets*} in the course of the conversion of liabilities into assets. It is necessary to take into account that a universal bank belongs to the class of very complex stochastic self-adjusting systems with a great number of feedbacks (according to Beer [3]). With the course of time, the quantity and complexity of links increase (along with the extension of a

bank branches network, the advance of new products on the market of banking services etc.).

On the other hand, a bank is possible to represent as a non-stationary finite-dimensional system with continuous time (Kalman [6]) because the real economical processes flow in continuously varied time. Time is one of the parameters of the applicable models; the obvious necessity of the usage of a time factor is determined by the presence of inflation processes and the depreciation of money during a period of time.

Thus, within the framework of Forrester methodology and relying upon the our precursor articles [8]-[9], purpose of the present research is determined as the construction of a high level model of a bank by means of system dynamics in which the bank is modeled by a set of queuing systems.

## 3. Some foundations and model

In the first place, the nature of a bank's behavior is determined by its info-logical structure reflecting technological aspects of business processes along with the corporate policy and traditions (that directly or indirectly determine the process of decision making). It is applicable to the transformation of financial flows inside a bank first of all.

In consequence of this, a simulation process of the indicated transformation requires the fulfilment of the following steps:

i)    the design of the bank skeleton diagram, including major sources of amplifications and delays for input-output flows together with information feedbacks;

ii)   the detection of the basic resource flows (the staff of the bank, money resources as assets and liabilities separately, client applications for bank services, equipment and materials, and also associated information flows);

iii)  the formalization of administrative communications in the form of the systems of differential equations derived from the use of Forrester's

categories {*stock*; *flow*} (in full agreement with the a methodology of system dynamics).

According to [8], we shall remark that bank's organizational structure together with delays of the administrative solutions and operations, and also the business rules, can be mapped to the generalized view by means of some algebraic construction, homomorphic to the modelled system relative to the set of predicates defined on the system. For an arbitrary time $t$, the bank can be described by an aggregated index of productivity $D(t)$ that corresponds to the bank state at some point of $k \times n$-dimensional financial space $\mathbf{D}^{k \times n}$ (where $k$ denotes a number of economical indicators for evaluation, and $n$ denotes the quantity of bank branches). Thus, during the present research the main emphasis is made on a quite high level of abstraction, namely the set of state variables (Forrester's stocks) and time will generate the space in which the bank phase trajectory (flows in dynamics) will be realised.

Our reasoning based upon Forrester's thesis that the banking balance is a level in feedback-loop system. Thereby, it is possible to define the aggregated levels describing financial, material, and human resources of a financial institution: staff, clients with their requirements for bank services, assets, liabilities, equipment, bank office buildings, information resources. Each of listed stocks has associated flows, for example: a growth or a reduction of the number of the bank staff; movement of staff inside the bank; oscillations of clients quantity etc. [9]. The typical bank financial flows are selected similarly: receipts of the credits from National Bank, other domestic and foreign financial institutions, depository receipts from the individual households, non-cash settlements and money transfers, etc.

To accomplish the evaluation of the dynamical characteristics of a bank in the system sense, we need to known the nature and values of delays for resource flows and administrative influences. These delays are often due to the features of the financial technologies (know-how) and document circulation in a particular bank, and are caused by human factors too (including both bank employees and clients). We assume that the process of granting some unit of the banking product to a client (meta-operation by [8]) consists of $q$ different elementary operations. In its turn, the

meta-operation fulfillment cost is a discrete function of a runtime of these operations and can be expressed in a matrix form. The dimension of a matrix $D$ of temporal parameters of the model is $q \times (k_1+k_2)$, where $q$ stands for a number of meta-operations (number of rows in a matrix), $k_1+k_2$ is a quantity of columns in a matrix (each of the columns is responsible for a particular kind of work time costs, $k_1$ represents a quantity of the applicable elementary operations executed by the bank staff, and $k_2$ denotes a quantity of different external delays).

Thus, matrix elements $d_{ij}$ represent the values of the type $j$ of time cost for the type $i$ of a manufacturing process (a meta-operation). In practice, besides delay sources, the sources of amplification in the system with $d_{ij} < 0$ can exist. In the general case, the values of $d_{ij}$ can oscillate about the average points (for example, they are increasing during tax payments).

After all, the total time expenses of manufacturing and of the promotion of a unit of the banking product (taking into account all delays and amplifications) can be expressed in the form:

$$d = \sum_{i=1}^{q} \sum_{j=1}^{k_1+k_2} d_{ij}$$

(1)

Likewise, we define a matrix $V$ of cost parameters of the model (a value of the element $v_{ij}$ is the cost of a unit of time for the type $j$ of an elementary operation or an external delay for the type $i$ of a manufacturing process). Then, the production costs of a unit of the banking product (taking into account only the fulfilment operations and unproductive losses of time) can be written as:

$$v = \sum_{i=1}^{q} \sum_{j=1}^{k_1+k_2} d_{ij} \times v_{ij}$$

(2)

The elements of a matrix $D$ are associated with substantial delays happening during the rendering of any service to clients of the bank including designs of the credit or depository agreements, the maintenance of clearing accounts, collections of bills, the implementation of interbanking payments, etc.

Having prescribed applicable input and intermediate variables for each stock (Forrester's level) and its flows, we are now in a position to initiate the parameterization of the simulation model of a banking institution. "The system description is translated into the level and rate equations of a system dynamic model" [5]. The rates of flows reflect the dynamics of the change of levels; the data on levels are input values for rate equations. It allows us to formalize the feedback-loop structure of a bank (more details in [9]). Roughly speaking, assets and deposit income participate in positive feedback loops of profit while liabilities and deposit expenses of bank participate in negative feedback loops.

The isolation of feedbacks loops allows us to describe processes that are happening in the bank management system. The tool being applied for this purpose is systems of ordinary differential equations (see also [7]). It is necessary to point out that having applied this method, we can search for hidden "bottlenecks" in a system more easily – by means of the analysis of a ratio between service rates (intensities) and bank service application rates. In fact, this approach can help us predict the appearance of bottlenecks in the future also; i.e., simulation model conducts to better understanding of banking business processes, and bank staff can receive the answer to a problem "What and why?" at any time and for every bank subsystem.

Note that we can't avoid completely the influence upon bank behavior of the random perturbations of an environment (and bifurcations arising from these perturbations [2]). Zulpukarov [10] pointed out that we use the advantage of phase space non-uniformity that allows us to distinguish areas where system dynamic model is applying almost wholly; for remainder areas, we may accept the probabilistic methods. On the other hand, the sudden stepwise variations of system's regular state at smooth variations of external conditions (in the sense of the catastrophe theory [2]) can been considered manifestations of Forrester's amplifications and long time delays.

In a perfect case, wholly generalized equations of a model should encompass all phases including both the changes of the bank structure and the changes of the mode of the interaction with an environment (first of all, changes of a boundary layer of a

system, bank's front-office). For example, it is necessary to perform beforehand simulations of representative banking situations: an excess accumulation of demand deposits and a downsizing of allocation of resources, an appreciation of tariffs rates of main bank transactions (tariffs are up to "the limit of tolerance"), etc. V. Arnold pays attention to the relevance of a similar simulation for the economical applications: "The optimization and intensification can result in a disastrous loss in stability" [2, p. 98].

By the way of illustration, we show a part of the system dynamic model of bank; namely, we attempt to describe **the promotion of a set of banking products among some categories of clients** (in the supposition, that it is a stochastic process with discrete states and continuous time). We make the following assumptions:

i)   in the case of continuous Markov circuits and Poisson events flow, the densities of transition probabilities represent the intensities of events flows;

ii)  if the number of system states is finite (although being a large value), then under the assumption of the persistence of intensity of events flow at $t \rightarrow \infty$ some limiting steady-state regime is established;

iii) system components are uniform (within the limits of considered categories of clients).

Thereby, we can take advantage of Kolmogorov equations to formalise a mathematical model. It is an important step towards the model that naturally combines the discrete view of the states of a bank as a set of queuing systems with the continuous view of the operational work-time of a bank. Along the way, this approach makes it possible to take into account the interactions between the objects of simulation and an input stream of the service applications (for example, the suspension of the service of clients during staff overload, or the increase of result indicators for this product beyond the planned range). Extra advantages of this approach are the relative simplicity of the model (the set of equations is easily introduced directly on the basis of the labelled graph of bank system states), and also

the capability of the model to account for both the specialized applications service centers (bank staff) and the operational load.

The quantity and quality of services submitted to the clients of Ukrainian banks is rather insignificant, therefore our model looks rather simple. Let client base consist of a set of $N$ homogeneous elements (clients), $\varepsilon_i$ be a  state of an element (the depository agreement is concluded; the deposit income is repaid; deposit and accrued interest are repaid completely; the agreement is prolonged etc.),  $\delta$ be the intensity of the update of the state $\varepsilon_0$ (signing of the first agreement for a new client), $m_i$ be the expectation of the number of elements located in a state $\varepsilon_i$ ,  $\lambda_{ij}$ be the intensity of flows of clients for the transition  $\varepsilon_i \rightarrow \varepsilon_j$. We set the sum of expectations $m_i$ equal to $N$ as a normalizing condition.   Then it is possible to represent the system of differential equations in the form:

$$\frac{dm_i}{dt} = -\sum_{k \in K} m_i \lambda_{ik} + \sum_{l \in L} m_l \lambda_{li} \tag{3}$$

In the latter differential equation, $K$ is the set of states for which transitions from $m_i$ are exist; $L$ is the set of states for which transitions into $m_i$ are exist; on the right side of the equation,  the value $\delta$ should be included for the state $m_0$. The input data for an initial estimation of the intensities of client flows and expectations can be obtained  both from the time records on the activity of staff of a particular bank (for the period of 2 to 4 weeks) and from the applicable operational documentation and databases.

Let's note that in practice the shift of bank's staff attention to yet not "enveloped" clients and the concentration of efforts on them is happening relatively slowly due to the delays of trusted data on the state of the client sector.  At the same time, by no means real clients are passive sacrifices of bank institutions; vice versa, they counteract by individually estimating financial companies and by selecting particular banks. It is common for countries with developing banking system (Ukraine, Russia etc.). Thus, we need to make such a correction of business processes

that takes into account the bank resources reallocation and the "resistance" of potential clients.

Having applied the methods of operations research [1, pp. 322-325], we can write the equations for interactions in the system {*banks*; *clients*}. For example, expression for banks (for clients analogously):

$$\frac{dm_B(t)}{dt} = -p_C \times \lambda_C(t - \tau_C) \times m_C(t - \tau_C) \times \frac{m_B(t)}{m_B(t - \Delta_B)} \tag{4}$$

Here, $p_B$ and $p_C$ are probabilities of success (attachment of new clients by a bank, and a selection of a new "good" bank by client), $\tau_B$ and $\tau_C$ are operation times for a bank and a client respectively, $\Delta_B$ and $\Delta_C$ are time delays in the course of attention switching for a bank and a client respectively, $\lambda_B(t-\tau_B)$ and $\lambda_C(t-\tau_C)$ are the productivities of the parties at the interaction start time, $m_B(t-\tau_B)$ and $m_C(t-\tau_C)$ are numbers of active interested banks and clients respectively at the interaction start time, $m_B(t-\Delta_B)$ and $m_C(t-\Delta_C)$ are the numbers of active banks and clients respectively at the time of information receipt, $m_B$ and $m_C$ are the numbers of active banks and clients respectively that are not yet in interaction at time $t$.

The following conditions should be added: 1) $m_C(t-\tau_C) = N_C$, $\quad 0 \leq t \leq \tau_C$ ; 2) $m_B(t-\tau_B) = N_B$, $\quad 0 \leq t \leq \tau_B$ ; 3) $m_C(t-\Delta_C) = N_C$, $\quad 0 \leq t \leq \Delta\tau_C$ ; 4) $m_B(t-\Delta_B) = N_B$, $\quad 0 \leq t \leq \Delta\tau_B$ ; 5) $N_B$ and $N_C$ are primary numbers of banks and clients respectively that are beyond the confines of the domain of partner relations.

Without being too bold, we can state that this approach is still applicable to more abstract schemas of bank service in the system {*deposit owners*; *banks*; *loaners*}. To our regret, it goes beyond the frameworks of the present article and requires a special consideration. It remains to note that the implementation a system dynamic model of a bank in the form of a set of queuing systems (similar to the one described above) using the simulation systems (Vensim, GPSS World, AnyLogic™ etc.) enables the reconfiguring of banking business processes before the development of the negative tendencies.

## 4. Conclusions and Discussions

The past 50 years witnessed substantial research activities directed at improving the method of system dynamics for the economic analysis. During economic crises, the tools that are actionable, quickly deployable and parsimonious could be highly valuable. A realistic assessment of computer expert systems user's skills suggests that one promising direction of  researche is the creation of simulators supporting everyday activity of banking personnel. System dynamics is such an instrument for any administrative level including  managerial decisions and actions on  different levels.

The simulation  toolkit facilitates optimization of a bank's organizational structure, operations, their technological directions and supporting information flows. All of these leads to  profit growth and decreased need in material, financial, and human resources. Besides providing the adequate characteristics of the current and future bank activities, the system dynamics method application allows proceeding further with the exploration of the management strategies and decisions. This could ensure successful economic activity (i.e., providing a desirable value of the effectiveness criterion). The application of these tools by decision makers promotes more precise and timely comprehension of the latent reasons of  bank problems. The system dynamics technique also enables faster and more precise localization of the sources of  malfunctions, and a subsequent execution of a calculated targeted liquidation of redundant or non-productive bank branches (or a measured correction of the business  rules).

The hybrid method proposed in the paper is a combination of the system dynamics philosophy, queueing theory, and Kolmogorov equations apparatus. The paper provides many opportunities for further exploration. For example, the approach developed in the paper needs to be applied to concrete simulation scenarios.

This approach may be used to implement the following procedures (requires further research):

i)      the optimization of the tasks and their volume for banking branches' staff;

ii)   the rationalization of a bank's infrastructure (branch network, ATM-network, POS-terminal network etc.);

iii)  operational information aggregation for planning and forecasting;

iv)   business simulation games for the hiring and the training of the candidates for the vacant positions in a banks;

v)    teaching applications;

vi)   the analytical phase during the design or the redesign of banking information systems.

There is no magic bullet to cure banking problem in either developed or transitional economies. However, the proposed procedures might increase bank efficiency tactically and strategically. They might facilitate a decrease in operational expenses, providing gradual steps towards the "personnel-free front-office" paradigm (on the basis of intellectual ATMs coupled with other measures).

**Acknowledgments**

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