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SIMULATION OF AUTOMATED REAL-TIME GROSS INTERBANK SETTLEMENT

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Abstract. The aim of this paper is to analyze algorithms for the automated real-time gross interbank settlement (RTGS). One can change the efficiency of settlement systems by perfecting the processing of settlements and/or implementing rules for solving the gridlocks, or by applying the tools of refinancing and reservation. We focus on the settlement simulation of the Trans-European Automated Real-time Gross Settlement Express Transfer system (TARGET2). The system of modelling, simulation, and optimization of settlements (Bakšys and Sakalauskas 2007b) is applied in the simulation of TARGET2, estimating the parameters of simulation according to the real data.

Keywords: interbank payments, settlements, simulation of settlements, payments flow, algorithms of interbank settlements.

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1. Introduction

The development of new information technologies allows the agents of economy to effectively manage the assets in bank accounts. Settlements systems of various architectures and processing are used to meet the demands for efficient performance of payments (Leinonen and Soramaki 2003). Development of economy, globalization of finance markets and growth of money mass have an influence on the settlement processes. In the period of 2002–2006, the volume of non-cash payment transactions in the euro zone was growing by 34.9% and their value increased up to 41.7% (ECB 2008). The new conditions impose on the settlement systems additional demands for liquidity, reliability, and economy. To satisfy the general monetary policy, such tools of payments are necessary that enable us to perform the transactions between the national central banks (NCB) and other banks safely and opportunely, and

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induce the solidarity of money markets of the Euro zone. A rapid development of the process of eurointegration and the outlook of expansion of the Euro zone have imposed new requirements on the national central banks to integrate national payments and settlement systems (NPSS) into a unified Trans-European automated settlement system. The mentioned aims in the Euro zone are accomplished by joining the NPSS to the Trans-European Automated Real-time Gross settlement Express Transfer system (TARGET).

The non-cash payments were growing in the market of payments of Lithuania, too. Compared to 2006, in 2007 the volume of payment transactions in the Payment and Settlement System of the Bank of Lithuania was growing by 25.3% and their value increased up to 42.7% (Bank of Lithuania 2008). The mentioned factors induce the banks to constantly pay much attention to the improvement of settlement processes.

One of the areas of the settlement process perfection is analysis of an effective service of transactions flow by using the algorithms of queue ordering. The financial institutions use various algorithms of queue ordering in search for the optimum method of settlement. In the world practice of settlements, the queue reordering and liquidity restoring algorithms are used. Frequently, in a settlement process the queue reordering and liquidity restoring algorithms are jointly used by choosing the optimal combination of these algorithms in response to the requirements of the settlement system.

The rate of payments flow and aspirations of NCB to improve the payments and settlement systems, to meet the requirements of systems make this subject of investigation topical both in theory and practice.

The objective of the article is to develop simulation tools and analyze the efficiency of settlement algorithms in reordering the queue of transactions.

The RTGS processes are analysed by Renault and Pecceu (2007), Koponen and Soramaki (2005), and Leinonen and Soramaki (2005). Most of mentioned researches are based on the analysis of statistical data of settlement process. We analyse settlement algorithms using the system of modelling, simulation, and optimisation of settlements (Bakšys and Sakalauskas 2007a), which allow the stochastic simulation of payment flow.

2. The structure of the interbank settlements system

The procedures of account debit and credit perform the transactions of settlements. The assets move from one correspondent account to another and get on the final receiver's account (Soramaki *et al.* 2007). Some participants of the system generate transactions, while the others receive them. Therefore, two flows of settlements and their influence on the participants of the system are different (Angelini *et al.* 1996). These flows change the balance of settlements.

The basic purpose of payments and settlement systems is to guarantee an efficient settlement process. The settlement process in a settlement system consists of the following phases (Leinonen and Soramaki 2003):

- submission;
- entry;
- booking;

- queueing;
- gridlock identification and resolution;
- queue allocation;
- end of the settlement.

In the first phase, the participants of the system send a transaction to the system for processing. In this phase, an internal transaction queue is formed as well as the participants of the queued system are arranged in the transaction priority. The real data of one order of the payment and settlement system $y = (ID, a, b, t, p, e)$ consist of:

- the application number *ID*;
- the application sender's name or code *a*;
- the application receiver's name or code *b*;
- the application submission time and date *t*;
- the application volume *p*;
- complementary information *e*.

The complementary information is assigned to the receiver of transaction. Using this information, the account of the participant is credited to the final transaction receiver.

In the entry phase, the settlement instructions, received by senders, are estimated and the methods of transactions are chosen. In this phase, the possibilities of performing transactions as well as that of splitting and queueing them are analyzed. The transaction sender is informed on the status of transactions and the settlement process.

During the entry phase, the booking on a participant's account is executed. In this phase, the account of a transaction sender is debited and the account of a transaction receiver is credited.

In the queueing phase, unfulfilled transactions are queued. In this phase, the various settlement algorithms (i.e. splitting, queue reordering) are used.

In the gridlock identification and resolution phase the algorithms for solving the task of the transaction queue are applied using simulation of the execution queue of transactions. In this phase, the gridlocks of transactions are identified, if a transaction cannot be carried out due to the temporary illiquidity on the participant account in the settlement system. The temporary illiquidity on the participant account in the settlement system can be solved by reconstructing the transaction queue and settlement processing.

In the queue allocation phase, the queued transactions are realized as soon as they become eligible for booking.

In the end phase of settlement, the day balances of participants are made up and the final list of unfulfilled transactions created.

The structures of payment processing and the settlement system can be analyzed according to the complexity of these systems. The basic elements of submission, entry, and booking phases are available in most systems of settlement. The queueing and queue allocation phases depend on the availability of settlement algorithms and allocation modes. The payment and settlement system consists of the system operator and participants (banks, unions of credit, and other institutions of finance and credit). The major distinction between different interbank payment systems is whether a system is operating on a net or gross basis, or payments are processed individually in the batches (Lacker *et al.* 2003). The most usual 3 pure implementations of these principles are: real-time gross settlement (RTGS), time-designated net settlement (TDNS), and continuous or secured net settlement (CNS). One can change the efficiency of settlement systems by perfecting the processing of settlements and/or developing settlement algorithms, or by applying the tools of refinancing and using reserves of requirements (Berger *et al.* 1996), (Freixas and Holthausen 2005). In the TDNS, settlements are realized in the set intervals of time. In the real-time systems, settlements are processed continuously. Interbank settlement transfers in RTGS systems are directly booked on the central bank accounts: i.e. payments and settlements are processed simultaneously (Angelini 1998). In CNS systems, payments are booked immediately, while the final settlement, e.g., with the central bank money, is typically delayed until the end of the day.

3. Settlement balance

The participants of a settlement system comprehend the system as the flow of sent and received transactions that change the settlement balance of participants (Soramaki *et al.* 2007). The value of δ_i is called as the net balance of bank *i*. The net balance of bank *i* is the total sum of money that other banks send to the bank *i* minus the total sum of money that the bank *i* sends to other banks (Shafransky and Doudkin 2006; Bakšys and Sakalauskas 2007d).

$$\delta_i = \sum_{j=1}^{n}\left(\sum_{k=1}^{n} p_{ij}^{k} X_{ij}^{k} - \sum_{k=1}^{n} p_{ji}^{k} X_{ji}^{k} \right). \tag{1}$$

Denote by n the number of banks that are participants of the settlement system. Further we use the term "payment" instead of "payment order", for simplicity. For $i, j = 1,..., n$, let l_{ij} be the number of payments from bank *i* to bank j. Clearly, $i \neq j$ in all the cases where we are considering a pair of banks *i* and *j*, so further we will not mention it. Denote by p_{ij}^{k} the sum of the k^{th} payment from bank *i* to bank j, $k \in \{1,...,l_{ij}\}$, and by d_i the sum of the covering money deposited by the bank *i*. Introduce a variable $X_{ij}^{k} \in \{0,1\}$, $i, j = 1,..., n$, $k = 1,...,l_{ij}$. Here $X_{ij}^{k} = 1$ denotes that the k^{th} payment from bank *i* to bank *j* is included into the set of settled payments. Respectively, $X_{ij}^{k} = 0$ means that the payment is not included into the set.

Available funds d_i are the funds available in the settlement accounts of a system participant held with the central bank, required for settling a request, when applying the fund usage restrictions set to the system participant, if any. The Central bank or the system operator install the available funds d_i to guarantee the fulfilment of payments and stability of the settlement system.

The liquidity of participants and intensity of gridlocks depend in essence on the settlement balance (Bakšys and Sakalauskas 2007c). If at least averages of income and outcome payment flow for one participant are different, $\sum_{j=1}^{J} \mu_{ij} \neq \sum_{j=1}^{J} \mu_{ji}$, then the matrix is unbalanced.

4. A group of settlement algorithms

The operators of a settlement system use different settlement algorithms to guarantee an efficient settlement process. The settlement process algorithms are divided into the following basic groups (Leinonen and Soramaki 2003):

- submission algorithms (SUB);
- entry algorithms (ENT);
- settlement algorithms (SET);
- end-of-day algorithms (END).

The task of the submission algorithm is to determine which transaction is next to being processed from all the pending transactions in all systems. It can be understandable as the process in which the bank decides, which is the next transaction to be submitted for processing in the systems. All other algorithms are specified at the system level. The entry algorithms are used to perform the initial processing of each transaction. The splitting algorithms (SPL) and the injection algorithms (INJ) can be used with ENT algorithms. SPL split a large transaction into sub-transactions according to specific rules. INJ transfer liquidity between the ancillary and main systems. Queue release algorithms, SPL, INJ, Bilateral off-setting (BOS) algorithms, partial netting algorithms (PNS), and multilateral netting algorithms (MNS) are used with SET algorithms. Queue check and fetch of transactions from the waiting queue in the given order once an account, when participant has received more liquidity attempts, settle all the queued transactions in one netting event. BOS checks and fetches transactions from the waiting queues that can be bilaterally off-set. PNS seeks to settle a part of the queued transactions. MNS attempts to settle all the queued transactions in one netting event. The end-of-day algorithms process the final steps during a day or a settlement cycle.

5. The flow of transactions and its management

The flow of transactions influences the requirement on liquidity and the position of credit (Flannery 1996). The main purpose of an advanced settlement system is a decrease of general risk in the system and an increase of settlement speed (Schoenmaker 1995). To achieve this aim the procedures of reorganization of transaction flow are performed. The need for liquidity is different in each settlement system (Bech and Garratt 2003). The CNS system without settlement delay requires more liquidity in comparison with the DTNS system, because in the CNS system, the transaction flows are continuous and the assets to make a settlement are necessary continuous, while in the DTNS system, a bilateral flow of transactions is concerted and settlements are processed in a set time by a bilateral netting process. Therefore, in the CNS system, a possibility to satisfy the liquidity by reorganizing the transaction queue without settlement delay is lost (Soramaki *et al.* 2007). In the systems with settlement delay the participants of the system are able to eliminate losses from transaction flows (Güntzer *et al.* 1998).

In the settlement market, the cost of short-term loan instruments is defined, therefore the main purpose of the participants of the settlement system is to adjust the transaction flow, so as to minimize the cost of liquidity and to satisfy all obligations (Humphrey *et al.* 2001). The high cost of short-term loan instruments compels the participants to avoid a deficit of liquidity at the end of a day balance and put up with the deficit of liquidity during the settlement period (Kahn and Roberds 1998).

The structure of transaction flow influences the position of liquidity and the size of credit risk in the settlement system of participants. Therefore, the procedures of monitoring and control of transaction flow are executed in the settlement systems (Blavarg and Nimander 2002).

The first step to control the transaction flow is an external system of participants in transaction submission (Soramaki *et al.* 2007). In this step, the operator of a settlement system makes a decision, when the submitted transactions of participants can be performed. The central settlement system of the operator has a subsystem of primary submission of transactions. The external system of participants sends the transaction flow to this subsystem. The operator sends the transactions received from the primary submission subsystem to the central settlement system following the additional information, presented by the participants (additional information may contain the time of the transaction processing).

Most often the transaction flow is processed by using an elementary method of FIFO means (first in, first out) (Güntzer *et al.* 1998). Since the transactions in the flow are of different priority and execution speed, the instructions define not necessarily the attendance in the discipline FIFO. Also, another transaction flow may be used for queueing methods. The transactions may be performed in view of the transaction value to fulfil small value transactions. In such systems the participant is able to join the transaction queue with respect to the priority of transactions.

Splitting of transactions establishes conditions for the most effective usage of liquidity. The process of transaction splitting can apply two main scenarios: establishment of the largest value of transactions and the use of full liquidity (Güntzer *et al.* 1998). In the first case, the largest transaction will be split. In the second case, the largest part of a transaction to be performed is determined.

By ordering the transaction queue in the settlement system, we can cause an increase of accumulation of transactions. The participant of the system may delay the transaction by decreasing the need for liquidity (Rossi 1995). The transactions can be postponed to the end of the settlement period. If most of the participants will postpone the transactions to the end of the settlement period, accumulation of transactions can be caused to the end of the settlement period.

6. Solving methods of gridlocks and deadlocks

A gridlock is a situation in which the failure of one of the banks to execute transfers prevents a great number of other participants' transfers from being executed (Koponen and Soramaki 2005). The solution of gridlock situations uses several algorithms: splitting of transaction, bilateral reorganization of bilateral transactions, full and partial net procedures.

The transaction splitting method has been mentioned as the method for controlling the transaction flow, but it may be also used for solving gridlock situations. Let two bilateral transactions be presented, when one of the participants has the necessary liquidity to fulfil the transaction. In this case, the splitting of transactions into available liquidity may be done by realizing a part of obligations. The increase of liquidity may render the possibilities to pursue other transactions and solve the existing problem of gridlock. An alternative method for solving the gridlock is reorganization of bilateral transactions. Then the transactions may be reorganized by setting the transaction priorities and adjusting the transaction volume in FIFO.

A completely multilateral netting method is the most common method for solving the gridlock. The principles of effect are booking of the gross transactions balance on the settlement account (James and Willison 2004). In case of insufficient liquidity, the method of partial multilateral netting is applied. By applying this method, some transactions of a participant are removed from the transaction queue. In this case, the realizable transactions are held in the queue. The transaction is temporarily removed from the queue until the participant acquires the necessary liquidity.

The methods of solving the gridlock depend on the available liquidity of a participant and the urgency of transactions. If the participants of the system have a sufficient liquidity, the queue of waiting transactions is short or missing (Vital 1996). In this case, the gridlock rarely occurs and the need for its solution is minimal. The usage of netting always requires to make up a queue of waiting transactions and to accumulate the sum of transaction to realize a settlement. If all the transactions are urgent and cannot wait in a queue, the participant has no alternatives to delay the transactions and must ensure the necessary liquidity to fulfil transactions without delay.

7. TARGET 2 settlement algorithms

The Trans-European Automated Real-time Gross settlement Express Transfer system (TARGET) has a decentralized structure that connects national RTGS systems and the ECB Payment Mechanism (EPM) (ECB 2007). TARGET2 provides the real-time gross settlement for payments in euro, with a settlement in central bank money. TARGET2 is structured as a multiplicity of RTGS systems.

In TARGET2 the flow of transactions is divided into several queues: highly urgent, urgent and normal payments. The selection of orders depends on the priority class to which it was designated by the system participant. Payment orders in the highly urgent and urgent queues shall be settled by the offsetting checks. The settlement procedure starts from the payment order at the front of the queue in cases, where there is an increase in liquidity or there is an intervention at the queue level (change of settlement time or priority, reordering the transaction queue). The transactions in the normal queue are settled continuously including all not settled highly urgent and urgent payments. Different optimization algorithms are used for the settlement procedure. If an algorithm is successful, the included transaction will be fulfilled; otherwise, the included transaction will remain in the queue. To process the payment flows in TARGET2, the following 3 algorithms are used (ECB 2007):

- "all-or-nothing" algorithm;
- "partial" algorithm;

- "multiple" algorithm.

The "all-or-nothing" algorithm calculates the overall liquidity position of each TARGET2 participant's payment account in view of all the sending and incoming payments, pending in the queue. If the balance of flows is negative, it checks whether it exceeds that participant's available liquidity. In the second step, the algorithm checks the observance of limits and reservations, set by each participant in relation to each relevant payment account. If the result of these calculations and checks is positive for each relevant payment account, all the payments simultaneously on the payment accounts of the participants concerned are settled.

The "partial" algorithm calculates and checks the liquidity positions, limits, and reservations of each relevant payment account in the same case as the first algorithm. If the total liquidity position of one or more relevant payment accounts is negative, the queued transaction is removed until the total liquidity position of each relevant payment account become positive. As soon as the positive liquidity position is recovered, simultaneously all the remaining payments on the payment accounts of the participants are settled. The extracting process starts from the participant's payment account with the highest negative total liquidity position and from the transaction at the end of the queue with the lowest priority.

The "multiple" algorithm compares the pairs of participants' payment accounts in order to determine whether the queued transactions can be fulfilled within the available liquidity of the two participants' payment accounts concerned and within the limits set by them. If the bilateral liquidity is insufficient, payment orders are postponed until there is sufficient liquidity. After performing the multilateral settlement positions are checked.

During the settlement day the algorithms are running sequentially. The processing sequence is as follows (ECB 2007):

- the algorithm "all-or-nothing",
- if the algorithm "all-or-nothing" fails, the "partial" algorithm starts,
- if the "partial" algorithm fails, then the "multiple" algorithm starts, or if the "partial" algorithm succeeds, the algorithm "all-or-nothing" is repeated.

8. Simulation of settlement

In this section, the simulation algorithm and results of simulation are presented. The simulation was carried out using the system of modelling, simulation, and optimization of settlements taken from Bakšys and Sakalauskas (Bakšys and Sakalauskas 2007a). During the simulation, the algorithms described in the Section 7 are realised. According to the transaction model used, the system generates flows of moments of bilateral payments by the Poisson distribution and the corresponding flow of payment volumes by the lognormal distribution (Bakšys and Sakalauskas 2006; Bartkutė *et al.* 2006). The parameters of the Poisson-lognormal model were estimated according to the real data and are as follows: $\mu = 7.813$, $\sigma = 2.189$.

The settlement algorithm is run in 3 steps. In the first step, we realize the algorithm "all-or-nothing". The balance δ_i is computed as follows:

$$\delta_i^l = \sum_{j=1}^{J} \left(\sum_{k=1}^{z_{ij}^l} p_{ij}^{k,l} - \sum_{k=1}^{z_{ji}^l} p_{ji}^{k,l} \right), \sum p_{ij} - \sum p_{ji} \geq 0, \quad (1)$$

where δ_i^l being the balance of the settlement day l, z is the number of payment from the i^{th} to j^{th} participant.

If condition (1) is not satisfied, then the second step is accomplished. In this step, the "partial" algorithm is realized. The balance δ_i is computed as follows:

$$\delta_i^l = \sum_{j=1}^{J}\left(\sum_{k=1}^{z_{ij}^l} p_{ij}^{k,l} - \sum_{k=1}^{z_{ji}^l} p_{ji}^{k,l}\right) - \max\left(p^l\right), \sum p_{ij} - \sum p_{ji} < 0. \quad (2)$$

If both conditions (1) and (2) are not satisfied, then the third step is fulfilled realising the "multiple" algorithm. In this case, the balance δ_i is computed as follows:

$$\delta_i^l = \sum_{j=1}^{J}\left(\sum_{k=1}^{z_{ij}^l} p_{ij}^{k,l} - \sum_{k=1}^{z_{ji}^l} p_{ji}^{k,l} - \max\left(p_{ji}^l\right)\right), \sum p_{ij} - \sum p_{ji} < 0. \quad (3)$$

The algorithms have been realized with real parameters of the settlement system participants. For simplicity, a settlement process of 3 participants has been simulated. During the simulation the influence of the initial correspondent account value on the coefficient of settlements as well as on dynamics of the correspondent account has been explored. The performance coefficient indicates the level of fulfilled transactions.

In Fig. 1, dependence of the performance coefficient on the temporary value of correspondent account is given. In this figure, the influence of the correspondent account value on transaction fulfilling is observed. The figure illustrates, that the growth of the correspondent account value improves the realization of transactions.

In Figs 2–4, dynamics of the correspondent account value is presented during the settlement process for the participants of the settlement system. The figures show that the values of the correspondent account of the 1st and 3rd participant are decreasing and the values of the correspondent account of the 2nd participant are increasing. This shows that some participants of the settlement system accumulate income, when other participants lose the liquidity.

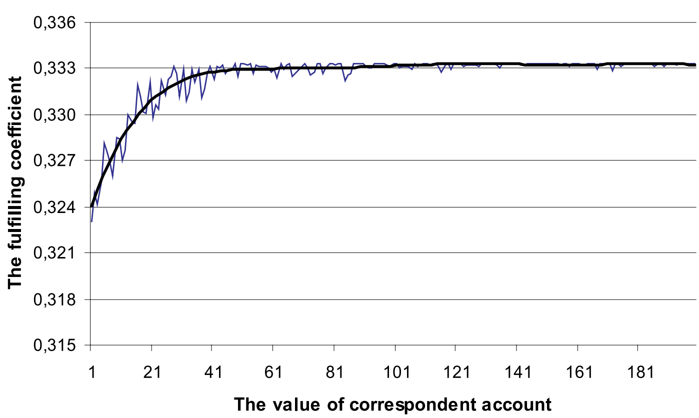

Fig. 1. Dependence of the performance coefficient on the value of the correspondent account

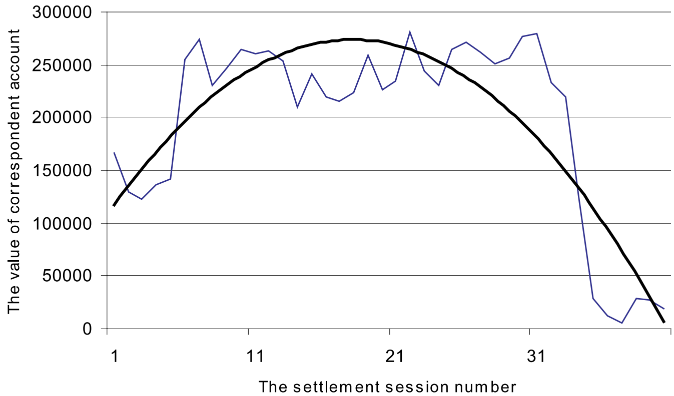

Fig. 2. Dependence of the value of the 1st participant correspondent account on the settlement session number

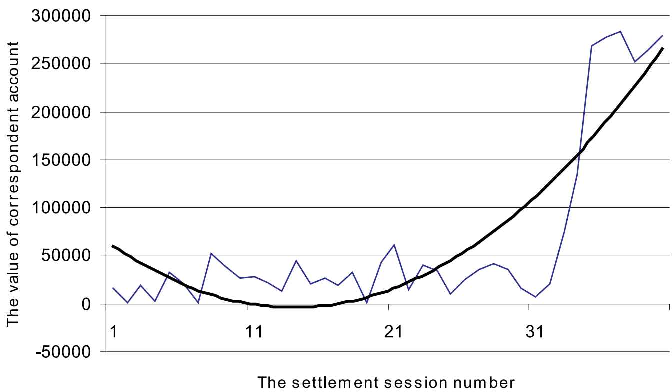

Fig. 3. Dependence of the value of the 2nd participant's correspondent account on the settlement session number

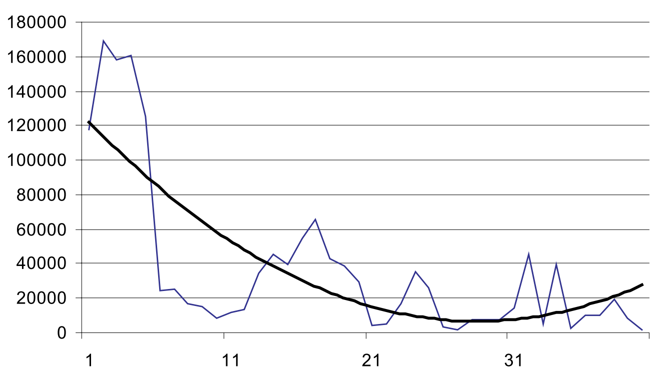

Fig. 4. Dependence of the value of the 3rd participant's correspondent account on the settlement session number

9. Conclusions

The results of simulation essentially depend on the balance of the payment intensity matrix. In the system with an unbalanced matrix, the participants have a different liquidity position and meet different intensities of gridlocks. Thus, in one cluster of participants the position on the correspondent account becomes positive, in a second cluster the participants necessarily require for liquidity at the end of the settlement day. Therefore, to the participants with scarcity of liquidity additional requirements should be applied. The value of requirements will be settled in view of the liquidity position at the end of the settlement period. The long-term negative liquidity position shows that the participant has outside incoming assets or is in the pre-bankrupt situation. The result of simulation shows that there exists an optimal value of the correspondent account which ensures the execution of all the transactions with a highest reliability.

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References

Angelini, P.; Maresca, G.; Russo, D. 1996. Systemic risk in the netting system, *Journal of Banking and Finance* 20: 853–868.

Angelini, P. 1998. An analysis of competitive externalities in gross settlement systems, *Journal of Banking and Finance* 22: 1–18.

Bakšys, D.; Sakalauskas, L. 2006. Modelling of Interbank payments, *Technological and Economic Development of Economy* 12(4): 269–275.

Bakšys, D.; Sakalauskas, L. 2007a. Modelling, simulation and optimisation of Interbank Settlements, *Information Technology and Control* 36(1): 43–52.

Bakšys, D.; Sakalauskas, L. 2007b. Study of the simulation and optimization system of interbank settlements, *Information Technology and Control* 36(4): 388–392.

Bakšys, D.; Sakalauskas, L. 2007c. The system for simulating interbank settlements, *Technological and Economic Development of Economy* 13(4): 323–332.

Bakšys, D.; Sakalauskas, L. 2007d. Modelling, simulation and optimisation of interbank continuous net settlements, in *Changes in Social and Business Environment*: Proceedings of the 2nd International Conference, November 8–9, 2007, Panevėžys, Lithuania: selected papers / Kaunas University of Technology Panevėžys Institute, Bulgarian Association of Management and Engineering, Koaceli University, Martin-Luther University ... [*et al.*]. Kaunas, 18–24.

Bank of Lithuania 2008. Monthly bulletin 2008/2. Bank of Lithuania. Vilnius, 2008.

Bartkutė, V.; Felinskas, G.; Sakalauskas, L. 2006. Optimality testing in stochastic and heuristic algorithms, *Technological and Economic Development of Economy* 12(1): 4–10.

Bech, M. L.; Garratt, R. 2003. The intraday liquidity management game, *Journal of Economic Theory* 109: 198–219.

Berger, A. N.; Hancock, D.; Marquardt, J. C. 1996. A framework for analysing efficiency, Risks, Costs, and Innovations in the Payment System, *Journal of Money, Credit, and Banking* 28(4).

Blåvarg, M.; Nimander, P. 2002. *Interbank exposures and systemic risk, Penning och Valutapolitik,* No. 2/2002, Sveriges Riksbank.

ECB (European Central Bank). 2007. Guideline of the European Central Bank of 26 April 2007 on a Trans-European Automated Real-time Gross settlement Express Transfer system (TARGET2) (ECB/2007/2). Official Journal of the European Union, L237, 2007.

ECB (European Central Bank). 2008. Statistics Pocket Book March 2008. European Central Bank. Frankfurt am Main, 2008.

Flannery, M. J. 1996. Financial crisis; payment system problems, and discount window lending, *Journal of Money, Credit, and Banking* 28(4).

Freixas, X.; Holthausen, C. 2005. Interbank market integration under asymmetric information, *The Review of Financial Studies* 18(2): 459–90.

Güntzer, M. M.; Jungnickel, D.; Leclerc, M. 1998. Efficient algorithms for the clearing of interbank payments, *European Journal of Operational Research* 106: 212–219.

Humphrey, D.; Kim, M.; Vale, B. 2001. Realizing the gains from electronic payments: costs, pricing, and payment choice, *Journal of Money, Credit, and Banking* 2(series 33): 216–234.

James, K.; Willison, M. 2004. Collateral posting decisions in CHAPS Sterling, *Bank of England Financial Stability Review*, December 2004.

Kahn, C.; Roberds, W. 1998. Payment system settlement and bank incentives, *Review of Financial Studies* 1(4): 845–870.

Koponen, R.; Soramaki, K. 2005. Intraday liquidity needs in a modern interbank payment system – a simulation approach, *Bank of Finland Studies* E: 14.

Lacker, Jeffrey M.; Weinberg, John A. 2003. Payment economics: Studying the mechanics of exchange, *Journal of Monetary Economics* 50: 381–387.

Leinonen, H.; Soramaki, K. 2003. *Simulating interbank payment and securities settlement mechanisms with the BoF-PSS2 simulator*. Bank of Finland.

Leinonen, H.; Soramaki, K. 2005. Optimising liquidity usage and settlement speed in payment systems, *Bank of Finland Studies* E: 31.

Renault, F.; Pecceu, J.-B. 2007. From PNS to TARGET2: the cost of FIFO in RTGS payment systems, in Leinonen (ed.). *Simulation studies of liquidity needs, risks and efficiency in payment networks.* Scientific monographs. E: 39.

Rossi, M. 1995. *Pricing intraday credit in real-time gross settlement systems*. Discussion Paper 211, Financial Markets Group, London School of Economics.

Shafransky, M. Y.; Doudkin, A. A. 2006. An optimization algorithm for the clearing of interbank payments, *European Journal of Operational Research* 171(Issue 3): 743–749. Elsevier.

Schoenmaker, D. 1995. *A comparison of alternative interbank settlement systems.* Discussion Paper 204, Financial Markets Group, London School of Economics.

Soramaki, K.; Bech, M. L.; Arnold, J.; Glass, R. J.; Beyeler, W. 2007. The topologyof interbank payment flows, *Physica A* 379: 317–333.

Vital, C. 1996. The architecture of real time gross settlement systems, In *Hong Kong Monetary Authority* (Hrsg.). *Global Payment Systems*, Hongkong, 23–32.

AUTOMATIZUOTŲ TARPBANKINIŲ REALAUS LAIKO SKUBIŲ ATSKIRŲJŲ ATSISKAITYMŲ IMITAVIMAS

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Santrauka

Tarpbankinių mokėjimų apimties didėjimas, augantis poreikis atlikti mokėjimus realaus laiko režimu kelia papildomų reikalavimų tarpbankinių atsiskaitymų sistemų technologijoms. Aktyvus elektroninių informacijos perdavimo priemonių diegimas į bankininkystę ir didelės atsiskaitymų dalies sutelkimas tam tikruose bankų sistemos centruose leido sukurti automatizuotus atsiskaitymo centrus – tarpbankinių lėšų pervedimo ir priešpriešinių mokėjimų padengimo sistemos. Straipsnio tyrimo objektas – transnacionalinių automatizuotų tarpbankinių atsiskaitymų algoritmų analizė imituojant atsiskaitymų procesą. Tyrimų metu buvo nagrinėjami transeuropinės automatizuotos realaus laiko atskirųjų atsiskaitymų skubių pervedimų sistemos (TARGET2) atsiskaitymų algoritmai. Atsiskaitymų procesui imituoti buvo naudojama atsiskaitymų modeliavimo, imitavimo ir optimizavimo sistema. Algoritmų tyrimo rezultatai gauti remiantis realiais mokėjimų ir atsiskaitymo sistemos duomenimis.

Reikšminiai žodžiai: bankiniai mokėjimai, atsiskaitymų sistemos, bankinių atsiskaitymų imitacinis modeliavimas.

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