Simulations on Optimization Methods
in Interbank Payment Systems

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Abstract

In this study a framework for efficiency comparison between different implementations of interbank payment settlement systems is constructed. The framework is used in analyzing the effects of queuing arrangements in real-time gross settlement systems and in comparing the efficiency improvements of optimization methods such as netting of queued transfers and splitting of payments. Also the extent of gridlocks in these systems is studied. A payment settlement arrangement is considered more efficient when for a given payment flow and liquidity, delay in payment settlement is reduced.

The study is based on results generated with a payment systems simulator developed by the author in the Bank of Finland. The simulator is a standalone application programmed with Visual Basic 5 and is capable of simulating a wide variety of hypothetical settlement and banking structures. The payment transactions used in the simulations consist of 100 days of actual payment data extrapolated from the Bank of Finland's interbank settlement system, the BoF-RTGS.

The results show that an RTGS system with queuing facilities and operating with the same liquidity as an end-of-day net settlement system results in substantially faster settlement of payments. Optimization features enhanced the operation of the system significantly. Splitting of payments enhanced the circulation of liquidity in the system and prevented the formation of gridlocks, thus reducing settlement delays substantially. The risk of gridlocks was overall found to be rather modest. The main effect of the netting of queued transfers was that it solved gridlock situations during the day and thereby reduced settlement delay. The partial netting algorithm, in which a subset of payments was settled if not enough liquidity to settle the full net position was available to the participants, was found to be much more efficient than the full netting alone.

Keywords: payment systems, real-time gross settlement, liquidity, optimization methods
# Contents

Abstract ....................................................................................................................... 1

1 Introduction ............................................................................................................. 4

1.1 Background and Outline of the Study ................................................................. 4

1.2 Interbank Payment System Designs .................................................................. 6

1.3 Objective of the Study and Prior Research ....................................................... 8

2 Liquidity and Risks in Interbank Payment Systems ............................................. 12

2.1 Sources of Liquidity .......................................................................................... 12

2.2 Risks in the Provision of Liquidity .................................................................... 14

2.3 Boundaries for Liquidity Needs ......................................................................... 19

3 Liquidity Optimization Methods .......................................................................... 27

3.1 System-based Optimization Methods ............................................................... 28

3.1.1 Queuing of payments .................................................................................. 28

3.1.2 Net settlement of queued payments ......................................................... 29

3.1.3 Splitting of payments ................................................................................. 31

3.2 Action-based Optimization Methods ............................................................... 32

4 The Simulator and Data Used .............................................................................. 34

4.1 Overview of the Simulator ................................................................................ 34

4.1.1 Account holder scenario .......................................................................... 36

4.1.2 Settlement scenario .................................................................................. 36

4.1.3 Systems scenario ....................................................................................... 38

4.2 Components of the Simulator .......................................................................... 39

4.2.1 Simulation run .......................................................................................... 41

4.2.2 System check ............................................................................................. 43

4.2.3 RTGS system ............................................................................................ 43

4.3 The Simulations and Data Employed ............................................................... 46
1 Introduction

1.1 Background and outline of the study

Over the past few decades, financial activity has increased significantly. This is mainly due to technological advance in computer and communication technologies, deregulation of financial markets and innovations in financial instruments. This growth has contributed to a substantial increase in numbers of payments within and between countries. Along with the growth in numbers of transactions, we have witnessed an increase in awareness of the credit, liquidity and systemic risks inherent in funds transfer systems.

In trying to reduce risk, interbank payment systems are shifting from net settlement systems to a greater reliance on gross settlement, in which payments are settled individually and sequentially. In net settlement incoming and outgoing payments are netted against each other and only the net balance is transferred between the banks. It is widely accepted that real-time gross settlement reduces risks associated with the settlement of payments. However, another result is that the number of payments that is processed is larger. Final settlements take place sooner and settlement risks are reduced, but it is also the case that more liquidity is usually required than in a net settlement system.

Liquidity usually involves costs, which motivates banks to minimize their liquidity usage. Central banks also have an interest in reducing participants' liquidity needs in gross settlement systems in order to encourage participation, as these systems entail less systemic risk than other systems. If liquidity costs in these systems are high, banks will have strong incentives to create private sub-netting systems instead of using settlement services provided by the central bank (Folkerts-Landau 1997).

The Bank of Finland's real-time gross settlement system (BoF-RTGS) was introduced in 1991, and was one of the first RTGS systems in Europe. In order to reduce risks in the Finnish interbank payment system, the Bank of Finland together
with the banks operating in Finland decided to further develop the system as part of preparations for the European Monetary Union (EMU). To study the effects of different concentrations of net and gross settlement and different optimization methods on a payment system's liquidity need, liquidity usage and settlement delay, a payment system simulator was developed in the Bank of Finland. The development and programming of the simulator has been the responsibility of the author. The simulator handles a wide range of settlement systems, banking sector structures and optimization methods. The effects of these features can be analysed separately in respect of individual banks or the banking sector as a whole.

The study is divided into seven chapters. In the next section of this chapter a brief overview of different payment settlement systems is provided. In the rest of the chapter the objective of the study is defined and prior research on the subject is discussed. Chapter 2 sets out the concepts and theory on the handling of intraday liquidity and the risks inherent in liquidity provision. Boundaries for the liquidity needs of system participants are also introduced. The framework introduced in this chapter forms the basis for the analysis of the simulations. In chapter 3 the assumed dynamics of optimization methods in RTGS systems are presented. Chapter 4 is devoted to the payment systems simulator and the data used in the simulations. In this chapter also the basic characteristics of the simulated payment systems are explained. More information on the simulator can be found in appendix 1. Chapter 5 presents the methods for calculating the liquidity boundaries used in the simulations and explains the indicators of liquidity usage and settlement delay. Chapter 6 is devoted to a presentation of the findings of this study. The results are organized into three sections. In the first section the introduction of payment queuing is analysed and in sections two and three the effects of the selected optimization methods of payment splitting and netting of queued transfers are studied. The most important results are summed up in chapter 7 and the applicability and limitations of these results is discussed. Finally some interesting, but still unresolved, questions that have arisen during this project are presented. A glossary of the key terms used in the study can be found in appendix 2.
1.2 Interbank payment system designs

A major distinction between various interbank payment systems is whether they are operating on a net or gross basis and whether payments are processed individually or in batches. The four pure implementations of these principles are real-time gross settlement, time-designated net settlement, continuous or secured net settlement and time designated gross settlement. Systems combining net and gross settlement and individual and batch processing are often referred to as hybrid systems.

A real-time gross settlement (RTGS) system is defined as a system where both the delivery of payment information and the final settlement of funds transfer take place simultaneously and continuously. Transfers are settled individually during the day without netting debits against credits. An RTGS system provides continuous intraday finality for the processed transfers (BIS 1997). Each participant of an RTGS system usually holds a settlement account, in which the debits and credits are made, at the central bank. If the sending bank does not have the covering funds to settle the payment the payment will usually not be settled. The processing of unsettled payments may differ significantly across systems. In general these payments are either rejected and returned to the sender for later input, or set in a queue. Queuing arrangements are described in section 3.1.1.

In a time-designated net settlement (TDNS) system the settlement of funds occurs on net basis at predefined points of time during the day or at the end of the day. The net position, which is the sum of payments, the bank has received until the end of the settlement period minus the payments the bank has sent, can either be calculated on bilateral or multilateral basis. In bilateral netting the number of funds transfers is a maximum of $n^2 - n + 2$, as for each bank the net positions against all other banks in the settlement system are calculated. In multilateral net settlement the number of funds transfers is a maximum of $n$, as for each bank only the net position against the
system is calculated. Although many of the G10 countries have introduced real-time gross settlement systems, according to Folkerts-Landau et al. (1996) most of the payment volume in the industrialized countries is settled using multilateral netting.

In continuous net settlement (CNS) systems payments are credited individually and immediately to the receivers' accounts but final settlements occur periodically or at the end of the day. These systems operate on settlement delay and the amount of risk involved depends on the net value of delayed payment settlements. To control the risks participants have often collateralized debt limits.

In a time-designated gross settlement (TDGS) type of system the payments are collected into batches and these batches are transferred between the banks without netting. The TDGS type of settlement is primarily used by the banks in international payments that go through their correspondent bank network. According to BIS (1997) however, systems in which payments are settled in real time during the day but remain revocable until the end of the day could be counted to belong into this category. The TDGS type of settlement is not covered further in this study as it is not used in any of the large-value payment systems.

Hybrid settlement systems try to combine elements from all of the above systems in order to achieve better performance than the pure systems alone. Hybrid systems try to optimize on the different settlement delay and liquidity costs associated with the pure systems. An RTGS system with optimization routines like netting of queued transfers could be described as a hybrid system as it combines net settlement with continuous gross settlement. The Finnish interbank payment system, the BoF-RTGS is a real time gross settlement system, which contains some hybrid features. Most of the new settlement system designs are of hybrid nature and all the payment settlement systems studied in this paper belong to this category.

1 The Group of Ten (G10) is made up of eleven industrial countries (Belgium, Canada, France, Germany, Italy, Japan, the Netherlands, Sweden, Switzerland, the United Kingdom and the United States) which consult and co-operate on economic, monetary and financial matters.
The emphasis of analysis in this study is on real-time gross settlement systems and hybrid systems based on real-time gross settlement. Time designated net settlement systems are used for reference as this has been the traditional design to settle payment transactions between banks.

1.3 Objective of the study and prior research

This study builds on an earlier study co-written by the author (Koponen-Soramäki 1998). In the earlier study randomly generated data was used and a wider variety of policy relevant questions were covered. This study deepens and expands some of the issues with simulations on actual payment data. The objective of this study is to develop a framework for the analysis of efficiency of interbank payment systems and to utilize the created framework in examining the effects of various optimization methods on liquidity needs of the system participants and settlement delays of payment orders. A payment settlement arrangement is considered more efficient when for a given payment flow and liquidity payment or settlement delay can is reduced. The settlement process is studied under normal operational conditions. Conditions situations relating to participant failures or general system crises lay outside the analysis.

Prior research on payment settlement systems is rather policy oriented and a large portion of it is conducted by central banks around the world, mainly in Great Britain, Italy and the United States. Most of the research on payment settlement systems can be categorized in one of the following three categories:

1. Descriptions of current arrangements
2. Analysis on the risks associated in these systems and central bank policy issues
3. Comparisons of net and gross settlement systems.

The settlement systems in use in different countries have evolved rather independently from each other. Until recently little effort to harmonize or standardize
these systems has existed. The first category consists of literature trying to describe
the systems in use in different countries. The goal has been to find common
structure, key similarities and differences in these systems. The study by Borio,
Russo and Bergh (1992) provides an overview of the common structure underlying
different settlement systems. Another earlier study is the survey by the Committee on
Payment and Settlement Systems (CPSS)\(^2\) on large-value funds transfer systems in
the G-10 countries (BIS 1990). The report by CPSS on Real-time gross settlement
(BIS 1997) is a good review of the concepts relating to RTGS-systems.

BIS (1989), Borio and Van den Bergh (1993) and Angelini et al. (1996) provide
good analysis of issues concerning the systemic risk in payment systems, the
emphasis being on netting systems. From the point of view of this study the papers
on systemic risk that simulate situations in which one or more participants of the
system fail to settle their obligations are of most interest. In Humphrey (1986) data
from the Clearinghouse Interbank Payment System (CHIPS)\(^3\) is used. McAndrews
and Wasilyew (1995) build on Humphrey (1986) and use generated data to study
factors, which affect to the systemic risk in a payment system. In Kuussaari (1996)
the extent and effects of a systemic crisis in Finland is empirically analyzed by
means of simulating bank failures. These studies share the same methodology, i.e.
they use ex post settlement data to assess the impacts of bank failures on other
system participants. The simulation model used in this study differs from the model
used in those studies in that it simulates the operation of a settlement system, not
specific events in it. In the simulations a bank may fail to settle, but it is output of the
simulation and not the input to the simulation.

The central bank policy issues studied relate among others to the intraday credit
policy of the central bank (e.g. Humphrey 1990, Furfine and Stehm 1997), to the

\(^2\) The Committee on Payment and Settlement Systems (CPSS) is a working group under the Bank for
International Settlement (BIS). It was established by the governors of the central banks of the G-10
countries to monitor and analyze developments in payment and settlement systems.

\(^3\) CHIPS is an interbank settlement and payment transfer system organized by the New York Clearing
House Association, a group of the largest city banks.
possible emergence of private intraday money markets (Rossi 1995) and the effects of these on monetary policy (Dale and Rossi 1996). The issue of externalities in payment systems, ie third party effects that are not internalized in the payment system such as the effects of delaying payments has been studied by Schoenmaker (1993). The studies by Angelini (1998) and Kahn and Roberds (1998b) relate to externalities as well, as in these studies the effects of insufficient or costly liquidity in an RTGS system on the settlement behaviour of the banks is analyzed. The common goal has been to find methods for the central bank to preserve the stability and smooth functioning of the payment system.

The third group of literature is studies, which compare the efficiency of net settlement and real-time gross settlement systems. Comparisons between the efficiency between different implementations of net or real-time gross settlement systems with queuing facilities are rare though. The research method of these studies is mostly analytical. Schoenmaker (1995) uses an analytical model to compare pure RTGS systems with net settlement systems with caps and loss sharing rules. Kahn and Roberds (1998a) compare the merits of net and gross systems in a framework of bank incentives and moral hazard problems. Kobayakawa (1997) analyzes whether there is a rationale for gross and net settlement systems to coexist in an economy. A recent study by Freixas and Parigi (1998) analyzes the trade-off between risks and efficiency in net and gross settlement.

Simulations which compare these two major type of systems or try to quantify the efficiency of different implementations of real-time gross settlement systems have been very scarce, perhaps due to data security issues and the demanding processing requirements of simulations. However some studies exist. Günzter et al. (1997) present several heuristic algorithms for bilateral and multilateral netting of payments in reference to the German payment settlement system Elektronische Abrechnung mit Filetransfer 2 (EAF-2). Ganz et al. (1998) simulate the efficiency of these algorithms in securities settlement. An earlier study by Boeschoten (1989) uses

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4 The Elektronische Abrechnung mit Filetransfer 2 (EAF-2) is the largest interbank settlement system in Germany and is operated by the Hessian branch of the German central bank, the Bundesbank.
simulations to assess the impacts of different queuing mechanisms in the Dutch interbank payment system, which operates on real-time gross settlement. Non-academic simulation exercises in the planning phase of a new system or in assessing the efficiency of existing systems have been done in several countries. The Swiss National Bank has used simulations in assessing the queuing mechanism in SIC\textsuperscript{5} (Vital and Mengle 1988, Vital 1990 and 1994), the Association for Payment Clearing Services (APACS)\textsuperscript{6} in refining the CHAPS\textsuperscript{7} system (Bowman 1995), and recently Banque de France in introducing its new RTGS system. Naturally the simulator used in this study has been used by the Bank of Finland in assessing the impacts of changes made to the BoF-RTGS as Finland joined the European Monetary Union.

\textsuperscript{5} SIC (Swiss Interbank Clearing) is payment settlement system operated by Telekurs SIC AG under the authority of the Swiss national Bank (SNB).

\textsuperscript{6} APACS (Association for Payment Clearing Services) is the industry body for the UK's major banks and building societies with 29 members. It oversees money transmission and has responsibility for the co-operative aspects of the UK payments industry, including plastic cards.

\textsuperscript{7} CHAPS (Clearing House Automated Payment System) is an electronic credit transfer system for sending payments between its members in the UK. Each payment is settled in real time across Bank of England settlement accounts, before the full payment message is forwarded to the receiving bank.
2 Liquidity and risks in interbank payment systems

2.1 Sources of liquidity

Banks need liquidity in settling their payments. This liquidity can be provided by the central bank or by the banks themselves in the money market. The central bank, depending on its policy preferences, can provide intraday liquidity to the banking sector by

1. allowing banks to use their required and excess reserves for settlement purposes,
2. allowing banks to overdraw on their settlement accounts, or
3. arranging intraday repos.

Many central banks use reserve requirements as a means of conducting monetary policy. A central bank may allow banks to use their required reserves and any excess reserves held at the central bank for settling payments. If required reserves are used for payment settlement, the average amount of liquidity in the settlement account must meet the requirement during the reserve maintenance period.

The central bank may also allow settlement system participants to overdraw on their settlement accounts, with or without interest charges. Partial or full collateralization of overdrafts may be required. If there is neither an interest charge nor a collateral requirement on overdrafts, the banks might overuse the credit facility and thus expose the central bank to the credit risk inherent in possible default by a payment system participant. Arrangement of intraday repos is analytically equivalent to required collateralization of overdrafts. Naturally, also any combination of these means can be used.

Both approaches, charging interest and requiring collateral on overdrafts, are used by central banks. In the European Union the agreed approach is to require full collateral
on an overdraft whereas, in the United States, the Federal Reserve banks grant uncollateralized intraday credit to participating banks but price it according to risks.\(^8\)

Several types of costs are associated with systems in which collateral requirements are attached to central bank credit facilities. Securities tied up as collateral give rise to opportunity costs because they are no longer available for trading and other purposes during the day. Because of this, the banks may be forced to hold inferior portfolios compared to those that would result from free choice. If the list of securities eligible as collateral is short, those on the list may generate lower returns due to their increased liquidity. The costs become obvious if the banks are forced to hold substantial amounts of such securities merely for settlement purposes. According to Schoenmaker (1995) a central bank policy to accept a wide range of securities as collateral can reduce the opportunity costs. Folkerts-Landau et al. (1996) argue that the cost of collateral depends also on the stage of development of the financial market. More highly developed markets generate greater payment volumes and create better trading opportunities and thus involve higher opportunity costs for collateral. In US-type RTGS systems, the cost of intraday liquidity takes the explicit form of interest payable on the average amount overdrawn during the day.

The banks can also obtain liquidity from or invest liquidity in the money market, on an hourly or longer basis, depending on the prevailing interest calculation period in the market. The cost of obtaining liquidity in the money market is explicitly priced though interest charges. If the banks use excess reserves held at the central bank for settlement purposes, the direct cost is the foregone interest.

In practice there are always some (implicit or explicit) cost factors inherent in liquidity. This makes liquidity a scarce commodity and creates incentives for banks to optimize their use of liquidity. The interest rate in the money market and the opportunity costs of collateral are determined by the markets. The interest rate

\(^8\) Rossi (1995) shows that the central bank effectively writes an European put option on the participants’ liquid assets by granting intra-day overdrafts and proposes a fee on the overdraft based on the value of this option.
charged on central bank credit is determined administratively according to risk and monetary policy factors. Thus these cost factors cannot be readily influenced by the banking sector.

There is one important free source of liquidity and this is provided by the payment system itself in the form of incoming payments. The faster liquidity circulates among the banks, the less the aggregate liquidity needed in the system. The more efficient the procedures and technical features, the less the system's need for liquidity injections from the outside.

Besides liquidity costs, there are also costs associated with settlement delays. Costs related to settlement delays consist of credit risk and possible opportunity costs. When the receiving banks accepts to credit the customer finally before receiving the interbank settlement it will at the same time accept a interbank credit risk. If the receiving bank has income generating investment opportunities for the delayed funds the delay will also mean foregone income possibilities. Costs occur also when the receiving bank stops customer payment processing until it receives the interbank settlement. Some customer payments are likely to be time-critical and any delays are likely to generate costs to the receiving bank and/or the sending bank. To the receiving bank these costs may be implicit, in the form of deterioration in customer service, or to the sending bank explicit, in the form of sanctions governing payment services.

2.2 Risks in the provision of liquidity

Regarding payment system participants' intraday liquidity needs, the relevant risks in respect of this study are credit and counterparty risks, liquidity and gridlock risks, and systemic risk. Other risks relating to operational or environmental factors are not covered here.
Counterparty risk is a type of credit risk that affects system participants in relation to each other. Both net and gross settlement systems can be designed to operate with various levels of counterparty risk (incl. zero). In a system with counterparty risk, the settlement of a payment is effected in two phases. In the first phase the payment is processed and payment information is sent to the receiving bank. The receiving bank irrevocably and finally credits the receiving customer’s account and bears the risk that the sending bank might not meet its obligation to provide covering funds later on. In the second phase this obligation is met via the transfer of covering funds (Leinonen 1998). As customers’ demands for immediate same-day value funds transfers have increased, banks, for competitive reasons, have become more willing to take on counterparty risks. Also, more extensive usage of delivery vs payment\(^9\) (DVP) in securities transactions and payment vs payment\(^10\) (PVP) in foreign exchange transactions may induce greater customer demand for intraday funding. This is because DVP and PVP require timely funding.

Because daily debt positions between banks can be very large, several measures have been taken to reduce risks in systems that operate on the basis of implicit debt relationships between banks, ie systems entailing counterparty risk. The following means of reducing and managing these risks have been implemented:

1. limits on the value of debt
2. collateralization of limits
3. loss sharing agreements.

If there are no limits on daily debt positions, there may be severe consequences in the event of a run on a bank. If the bank is still participating in the payment system, its customers will be able to transfer their funds from the crisis bank to other banks. If the other bank credits the receiving customer’s account before covering funds are

\(^9\) DVP is a mechanism that ensures that final transfer of assets does not occur without final transfer of the quid pro quo. Usually such an exchange is in monetary assets for securities.

\(^10\) PVP is another mechanism that ensures quid pro quo in a transaction. In this case one currency is exchanged for another.
transferred, it faces losses in the event of a failure in final settlement. This in turn could lead to a domino effect as other banks fail to settle their obligations for lack of liquidity in the form of incoming.

Placing limits on intraday debit or credit positions is a means of ascertaining in advance what the maximum losses would be in case of a bank failure. If limits are partially or fully collateralized, participants’ losses can be eliminated or kept at an acceptable level. Limits can be multilateral or bilateral. Bilateral caps are limits that participating banks set on debit/credit positions vs each other. One type of multilateral cap, referred to as a sender net debit cap, limits a participant’s net debit position vs the system. The value of a participant’s daily transfers to other participants cannot exceed its incoming transfers by more than the cap. In a system with bilateral caps, the theoretical sender net cap for a participant is the sum of the bilateral debit caps placed on it by the other participants.

Loss sharing rules or agreements provide for distribution of losses among surviving banks in the event of a default. If bilateral caps are in effect, one way of sharing losses is to apportion them according to credit positions vs the defaulter. Another way is according to payment values vs the defaulter. In the latter case, banks are less able to ration their risks because payment flows are generally exogenously determined.

Liquidity risk is the risk of a loss that arises when a bank’s liquid assets or its immediate access to credit are insufficient to cover its payment obligations. In Leinonen and Saarinen (1998) the liquidity risks are classified as variation risk, availability risk and gridlock risk. Variation risk arises because of wide variations in a bank’s liquidity needs, which means that at times it is unable to forward payments it has undertaken and must postpone the transaction. Availability risk arises when a market condition or a bank’s impaired financial condition reduces the amount of liquidity that the bank can obtain from the market to the extent that it has difficulty in making payments for which it is irrevocably committed. Leinonen and Saarinen
(1998) argue that poor liquidity management may lead to repeated payment delays, compensation claims and, if prolonged, to a loss of customers to rivals.

A type of liquidity risk that is associated particularly with centrally located queuing arrangements is gridlock risk. Gridlock has been variously defined. In BIS (1997) gridlock is defined as a situation in which the failure of one bank to execute transfers prevents a substantial number of other participants’ transfers from being executed. It should be noted that a queuing system itself does not cause liquidity risks or gridlock. Gridlock is a result of insufficient liquidity on the part of one or more participants. There are also various procedures that can be incorporated in the queuing system that will solve or prevent the formation of gridlocks. These procedures include splitting of payments and netting of queues, both of which are discussed in chapter 3.

The amount of intraday liquidity in an RTGS system can be measured from the perspective of the system or an individual participant. Table 1 summarizes the possible liquidity states of a payment system.

<table>
<thead>
<tr>
<th>NL_i</th>
<th>Queued payments get settled</th>
<th>Queued payments do not get settled</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0</td>
<td>(not applicable)</td>
<td>illiquid</td>
</tr>
<tr>
<td>≥ 0</td>
<td>liquid</td>
<td>gridlocked</td>
</tr>
</tbody>
</table>

A system is liquid if the net liquidity position of each participant is positive or zero. A bank’s net liquidity position at any moment is the net amount of its queued incoming and outgoing transfers plus the sum of actual funds that it has available for settling payments and any credit extensions. The system is illiquid if any participant is illiquid. How critical such illiquidity is depends on how time-critical and important the pending transfers are. All queued payments cannot be settled if any participant has a negative net liquidity position, assuming payments are to be settled in order of arrival.
In this study gridlock is considered to be a situation where every participant is liquid but payments cannot be settled because of a lack of sufficient funds on the part of one or more participants for settling their first payments in queues. A participant is liquid if its net liquidity position is zero or positive.

A simplified gridlock situation is illustrated in figure 1a. Banks A, B, and C each has liquidity worth ten units and one outgoing payment in a queue, with respective values of 15, 20 and 25. Payments are to be settled in the order A, B, C. Each bank has a nonnegative net liquidity position (\(NL_A = 20\), \(NL_B = 5\), \(NL_C = 5\)), ie the banks are liquid. Nonetheless, none of the payments or any subsequently queued payments can be settled before liquidity is injected into the system or some optimization method is applied.

Figure 1b depicts a situation where bank A has liquidity worth 15 and bank B liquidity worth 5. The net liquidity position of each bank is again nonnegative and the liquidity of the whole system is the same as in the previous case. However, all the payments are timely settled.

Another type of gridlock is 'self imposed gridlock'. This type results from the behaviour of the participants. Each participant relies on incoming payments as its only source of liquidity for settling its outgoing payments. Thus, in the extreme case in which each bank delays the sending of its payments, no payments are settled. Angelini (1994) argues that banks will tend to delay their payment settlement in
RTGS systems in an effort to minimize their usage of intraday credit. These types of situations are commonly referred to as prisoners’ dilemma situations, as optimal behaviour by each participant leads to an inferior outcome for all.

Systemic risk has traditionally been associated with money market disturbances that begin with a bank run, spread to other banks, and eventually pose a threat to the operation of the entire financial system. In the context of payment systems, systemic risk refers to the risk of loss that arises when the whole payment system or a substantial part of it ceases to function and the operational capacity of the society's payment services is significantly weakened. Such a disturbance can cause a chain reaction and may expand into an overall systemic crisis and can jeopardize the operation of the whole financial system and ultimately the real economy (Leinonen and Saarinen 1998).

Systemic risk may be caused by the failure of a critical part of a payment system, by the insolvency of a large participating bank or by a crash in a financial market for which settlements take place in the payment system. According to this causal breakdown, systemic risk can be categorized by origin as technology risk, bank risk or market-based risk. The increased volumes and integration of systems, the centralization of payment transactions and international linkages have increased the importance of systemic risk.

2.3 Boundaries for liquidity needs

The unit analyzed in the study is a settlement system comprising of banks and non-bank entities, which are commonly referred to as banks. The banks are continuously sending and receiving payments during the day and the settlement of these payments is recorded according to the established settlement rules at the settlement accounts employed. The intraday relationship between liquidity need and settlement delay in different payment settlement systems is analysed in this study within the framework depicted in figure 2.
The liquidity used by the settlement system (x-axis) consists of risk-free resources such as reserves held at, or intraday credit received from, the central bank. The corresponding delay in settlement (y-axis) is the time span between receipt of a payment order by the bank and final and irrevocable settlement of the payment.

Figure 2. **Relationship between liquidity usage and settlement delay in RTGS and TDNS systems without counterparty risk**

In the following, a framework used to analyse different implementations of real-time gross settlement (RTGS) and time designated net settlement (TDNS) systems is presented. The assumptions regarding banks' behaviour are:
1. Each bank has sufficient liquidity to settle all its payments during the day; hence no payments are postponed to the next day.

2. Banks do not queue their payments internally but enter them into the system immediately upon receipt of payment order.

3. Payments are settled in order of arrival without prioritization.

4. No payments are time-critical.

The first assumption is needed for closure of the settlement system and to enable comparison of systems that differ in respect of settlement implementation when the payment data are identical. The second assumption is needed in order to distinguish between queuing and nonqueuing systems. The assumption excludes internal queuing, i.e., queuing within banks' internal systems, so that queuing takes place only in a centrally managed queue. Calculation of settlement delay is based on the time span between payment origination and settlement. If prioritization is used, the payment flow is changed, as payments are not settled in a pure FIFO manner. On the average, the liquidity needs are the same as in a system without payment prioritization but daily variation exists as the settlement order of payments is changed. The time-criticality of payment increases the liquidity needs of the participants, as at some points of time external liquidity for the settlement of these payments has to be acquired. The subject of payment prioritization and time-criticality of payments is discussed in more detail in Koponen and Soramäki (1998).

The liquidity need and settlement delay in payment systems without counterparty risk are considered first.

Case 1. RTGS system with queuing

In a system with queuing, the banks need not have sufficient funds to settle their payments until the end of the day. In this case, the minimum liquidity needed for successful settlement of all of a bank's payments is equal to the excess value of
outgoing over incoming payments (absent gridlock\textsuperscript{11}). This is illustrated in equation 1 and represented by point B in figure 2.

\begin{equation}
LB = \min\left[0, \left(\sum_{i=0}^{T} P_i^{I} - \sum_{i=0}^{T} P_i^{O}\right)\right]
\end{equation}

**Equation 1:** Theoretical lower bound for a bank’s daily liquidity need in an RTGS system with queuing ($P_i^{I}$ = value of incoming payment, $P_i^{O}$ = value of outgoing payment)

At point B, settlement delay is at its maximum. A bank can reduce the delay in settling its payments by increasing its liquidity. As a bank increases its liquidity, it eventually reaches point C, which represents the level of liquidity needed for its payments to be settled immediately. The minimum liquidity that a bank needs for immediate payments settlement equals the absolute value of its daily minimum cumulative net amount of incoming and outgoing payments. If the bank’s net liquidity position is positive throughout the day, its external liquidity need is zero, since it receives sufficient liquidity in the form of incoming payments. If its net liquidity position is negative, the bank needs to acquire enough liquidity to cover the shortfall in order to settle its payments without delay. This is illustrated by equation 2 and represented by point C in figure 2.

\textsuperscript{11} An end-of-day gridlock can be solved by netting the queues and hence the same minimum would hold. It is also possible to solve a gridlock by splitting payments, but it may be necessary to have a splitting system that splits the payments into the smallest currency unit available.
The theoretical upper bound for a bank's daily liquidity need in an RTGS system with queuing is given by:

\[
UB = \min \left[ 0, \min_{i} \sum_{t=0}^{T} (P_i^t - P_i^o) \quad \forall \quad t \in [0, T] \right]
\]

Equation 2: Theoretical upper bound for a bank's daily liquidity need in an RTGS system with queuing (\(P_i^o\) = value of outgoing payments at time \(i\), \(P_i^l\) = value of incoming payments at time \(i\), \(T\) = end of day)

The curve segment BC shows the trade-off between liquidity usage and settlement delay. Liquidity must remain at least at the level of point B if all payments during the day are to be settled. Additional liquidity beyond point C is unnecessary because all payments get settled immediately.

Banks can theoretically choose any point on curve segment BC, according to their preferences. If a bank perceives the cost of liquidity to be high relative to that of settlement delay, it chooses a point near B and vice versa. Since a bank's payment flows can usually be only predicted at the start of the day and the exact pattern of payment flows cannot be known beforehand, the exact shape of the curve is not known until the end of the day.

Case 2. RTGS system without queuing

In an RTGS system without queuing, all the banks must have adequate liquidity to settle their payments immediately. A bank's liquidity need equals the upper bound for its liquidity in an RTGS system with queuing, i.e., the bank's minimum cumulative net amount of incoming and outgoing payments throughout the day. Because this amount of liquidity is needed for immediate payment settlement and any additional liquidity is unnecessary (since all payments are settled immediately), it represents both the lower bound and upper bound for the bank's liquidity in an RTGS system without queuing.
Case 3. TDNS system without counterparty risk

A bank's liquidity need in a time designated net settlement system with end-of-day settlement equals that of point A in figure 2. The liquidity need is the same as in an RTGS system with queuing, but the total delay in settlement is at its maximum. If the number of net settlements during the day is increased, settlement delay can be traded off for greater liquidity usage. The curve segment AC shows this trade-off. If the number of settlements is increased to the point where net settlement is executed after each transaction, the system becomes in effect an RTGS system without queuing. This is shown as point C in figure 2.

So far only systems without counterparty risk have been discussed. Properly designed real-time gross settlement systems are free of counterparty risk. Depending on the design of the system, a net settlement system can operate with or without counterparty risk. The z-axis in figure 3 gives the degree of counterparty risk in the settlement of payments. This risk encompasses the risks inherent in the implicit debt relations between system participants.

Case 4. TDNS system with counterparty risk

In figure 3, risk is introduced into the relationship between settlement delay and liquidity usage. A time designated net settlement system that operates with counterparty risk rather than liquidity is illustrated by the curve AD. By crediting customers' accounts before final settlement, the total settlement delay can be reduced. If all transfers are credited before final settlement, delay is eliminated and counterparty risk is at its maximum, as illustrated by point D in the figure.
Figure 3. Relationship between a bank's liquidity usage, settlement delay and counterparty risk in an RTGS or TDNS system with counterparty risk

The curve AD representing the trade-off between settlement delay and risk is convex to the origin. By crediting the payments of participants representing the smallest counterparty risk, delay in settlement can be reduced with less risk than if payments of the riskier participants are credited before final settlement. The shape of curve AC reflects the assumption of diminishing returns to increases in the number of net settlements during the day.

The area ACD in figure 3 represents the possible combinations of the number of net settlements during the day, the amount of risk a bank is willing to take, and the amount of liquidity used for settlements. An optimal settlement interval for net
settlement systems is derived in Angelini and Giannini (1993), under the assumption that the risk of a bank failure raises monotonically with the interval between settlements.

In this study, only structures in the xy-plane are simulated. This means that all the systems studied have the same level of counterparty risk (zero), which enables efficiency comparisons.

In actual payment systems at least some payments are likely to be time-critical, i.e. a delay in settlement will generate costs to the sending or receiving bank. All simulations in this study are done within theoretical bounds and without any payment prioritization. If time-critical transfers and payment prioritization are added to the system (ie assumptions 3 and 4 in section 2.3 are relaxed), the upper and lower liquidity bounds will change.
3 Liquidity optimization methods

A real-time gross settlement (RTGS) system is defined as a system in which the delivery of payment information and final settlement of funds transfer take place simultaneously and continuously. Transfers are settled individually throughout the day without any netting of debits against credits.

Because the liquidity used for settlement has an associated cost, optimization procedures have been proposed. The common goal has been to enable an RTGS system to run more smoothly with less liquidity. The optimization methods could be divided into two types: system-based and action-based.

The system-based methods are:
1 queuing of payments,
2 netting (clearing) of queues and
3 splitting of payments.

Action-based methods are:
4 codes of conduct between participants and
5 liquidity management

There are additional factors that influence the liquidity or, eg payment system opening/closing times, collateral requirements or pricing issues. These factors are usually externally determined by authorities and will not be addressed further within this context. All of the system-based optimization procedures are explained in detail in section 3.1 and a summary of action-based methods can be found in section 3.2.
3.1 System-based optimization methods

3.1.1 Queuing of payments

Each participant in an RTGS system holds a settlement account at the central bank, to which debit and credit entries are made. Payments without covering funds are not settled. The processing of these unsettled payments differs significantly across systems. In general, there are two ways to handle unsettled payments. These payments are either

1. rejected and returned to the sender for later input (in practice, these payments are entered into a queue managed by the participant) or

2. entered into a centrally managed queue.

In BIS (1997) queues are divided on the basis of management into centralized and decentralized queues. A further division on the basis of location into system and internal queues is also made. Centrally managed queues must have predefined rules and are usually managed by a central bank or other settlement agent. Queues with decentralized management are managed by system participants and may include features enabling liquidity management. Centrally managed queues may also include features that allow the banks to manage their own liquidity.

Different queuing systems have different rules for payments settlement. The Finnish RTGS system works on a ‘first in, first out’ (FIFO) basis. Payments entered sooner into the queue are settled sooner. Payments that are more time-critical than others can be given higher priority. Payments of the same priority level are entered into the same subqueue, and subqueues are settled in order of priority.
3.1.2 Net settlement of queued payments

One way to solve a gridlock in queuing systems is to execute a net settlement of all the queued payments. If each bank has enough liquidity to settle its net amount of queued incoming and outgoing payments, the queues are cleared and each bank’s account appropriately debited or credited.

A system is in gridlock if equation 3 holds for every bank but not all of the queued payments get settled. This happens when the system has enough liquidity but it is poorly distributed. By the definition in this study, a system is gridlocked only if the netting of queues would succeed. Netting will not succeed if at least one participant does not have sufficient liquidity. In this case, it is illiquidity that prevents settlement - not gridlock. The concepts of liquidity, illiquidity and gridlock were discussed above in section 2.2.

\[ \sum_{j=1}^{N} P_{j}^{I,i} - \sum_{k=1}^{M} P_{k}^{O,i} < L_i \text{ for each bank } i \]

Equation 3: Definition for gridlock (\( P_{j}^{I,i} \) = value of incoming payment in a queue for bank i, \( P_{k}^{O,i} \) = value of outgoing payment in a queue for bank i, \( L_i \) = bank i’s liquidity, \( N \) = Number of incoming payments for bank i, \( M \) = number of outgoing payments for bank i)

The netting of queues requires that information at least on values and senders and receivers of queued transfers be located centrally. This does not preclude management by participants of their own queues.

In a weaker form of netting, only a subset of all queued transfers is cleared. If there are numerous subsets that could be netted, it must be determined which are to be netted. In BIS (1997) it is pointed out, that because system participants may prefer different subsets, a legally tenable procedure must be agreed in order to solve such
situations. The agreement must also be binding on third parties under current legislation so as to avoid problems in the event of failure. This holds for any algorithm for netting queues.

The netting of queues reduces the system’s liquidity needs because the net position is by definition the minimum amount of liquidity that ensures the settlement of all payments. If queued payments are settled individually, a participant’s liquidity need could be as large as the gross value of all its queued payments. This would happen if the bank, for some reason, had to settle all of its outgoing payments before receiving any incoming payments. At the end of the day, there is no difference between net and gross settlement-with-queuing systems as regards the amount of liquidity needed to settle the day’s payments. This is true because all the payments must be settled before the end of the day and their effect on the account holder’s balance is by definition the net value of incoming and outgoing payments.

In the simulations, the algorithms used for netting queued payments are full and partial multilateral netting. If not enough liquidity is available for each accountholder to settle its net position, the full multilateral netting algorithm fails and all payments are left in queue. When the partial netting algorithm is applied payments are inactivated until a feasible subset of payments that can be settled with the available liquidity is found. Payments that are inactivated are left in queue and settled normally when cover is available. The partial net settlement used is a part of the multilateral netting algorithm used in EAF-2\textsuperscript{12} and corresponds to the algorithm inactivation run with criterion two in Güntzer et al. (1998).

\textsuperscript{12} The Elektronische Abrechnung mit Filetransfer 2’ (EAF-2) is the largest interbank settlement system in Germany and is operated by the Hessian branch of the German central bank, the Bundesbank.
3.1.3 Splitting of payments

Another way to make an RTGS system work more smoothly and to avoid gridlocks is to split large payments into several smaller ones.\textsuperscript{13} These smaller transfers then represent a source of liquidity to receiving participants. Without this feature, receivers must wait until the paying bank has accumulated enough liquidity, eg via incoming payments. This might in turn prevent a receiving bank from executing its own queued outgoing transfers. Such situations can lead to gridlocks that could have been prevented by the splitting of payments.

Figure 4. \textbf{Solving a gridlock by splitting payments}

The effect of payments splitting is depicted in figure 4. If an outgoing payment of 15 units from bank A is split into three payments of five units each, bank A is able to settle the first two payments. Bank B thus gets enough liquidity to settle its payment to bank C, which enables bank C to settle its payment to Bank A. In the end, final settlement of the original payment of 15 units is possible for bank A and the gridlock is solved.

The splitting of payments enables the banks to use their liquidity more efficiently at all times. Payments can be split centrally by the settlement agent or on a decentralized basis by the banks before they enter payments into the system. If the

\textsuperscript{13} The splitting of large payments is used for example in the Swiss interbank payment system (Vital 1994).
payments are split centrally, the splitting can be effected in a way that is transparent to the participants (Leinonen 1998).

The effectiveness of splitting payments for solving gridlocks depends on the technical features of the splitting. If the splitting is done to the smallest unit of account or payments are split so that all the available liquidity of every bank is used, this is as liquidity-efficient a way of solving gridlocks as the netting of queues. Less flexibility in respect of splitting means less efficiency. The more flexible the payment splitting, the greater the requirements in respect of computer power and advanced software. The technical costs of developing and maintaining such a system may outweigh the resultant savings in liquidity and settlement delay. The splitting of payments also requires tenable legal arrangements binding on all parties.

In the simulations, payments are split when they cannot be settled immediately and when their value exceeds the specified splitting limit. The processed payment is split into a minimum number of payments where each subpayment is of equal value and under the splitting limit. The calculation of settlement delay is in this case based on the time span between payment initiation and transferral of full cover of the complete original payment.

3.2 Action-based optimization methods

Action based methods include agreed codes of conducts between participants of the systems and liquidity management by the participants. The first of the action-based methods, ie rules or codes of conduct for settlement behaviour of participants, can make the payments flow smoother. Such rules can create more even flows of incoming and outgoing transfers for each bank and thus increase the circulation of liquidity. Liquidity management is the common name for the actions a bank takes in minimizing the costs associated with settlement.
Active liquidity management by banks is growing in importance because of the numerous payment systems that are available and, at least in Finland, the more extensive use of RTGS and increase in number of time-critical payments. In Finland some banks have developed their own liquidity management systems, which enable them to manage their incoming and outgoing payments and hence their liquidity positions.

The topic of active liquidity management or other action-based methods will not be discussed further in this study since the simulation of the banks behaviour would require another model.
4 The simulator and data used

4.1 Overview of the simulator

The simulation runs for this study were done using the payment systems simulator developed by the author in the Bank of Finland. The simulator is an explanatory model of payment settlement systems. It includes procedures for handling payments of actual payment systems and hence it produces exactly the same outcomes as an actual system with the same properties using the same input data. The simulator enables the study of the effects of different technical and policy features of a payment settlement system. Although the simulator is used in connection with this study to examine liquidity needs and settlement delays in selected systems, it can be used to study other aspects of payment systems as well. It should however be noted that the simulator is not an optimization model. No constraints are set on the results of model simulation and no cost calculations are included.

The simulator is programmed with Visual Basic 5 and functions as a stand-alone program. It uses Microsoft Access databases as its source for input data, for the saving and retrieving of scenario information and for its format for presentation of results. The program itself requires about 10 MB of hard disk space. Output databases take from 1 to 4 MB per 1000 payments settled, depending heavily on the settlement system simulated. The speed, using a standard PC with Pentium 2 chip and Windows NT, is about 3 to 5 minutes per day simulated. For information on the hardware and software requirements, see appendix 2.

The whole payment system in the simulator is divided into three logical scenarios, each with its own properties:

1 account holder scenario
2 settlement scenario
3 systems scenario
Properties of each scenario can be selected independently of each other. The parameters of each of the scenarios can be altered freely in order to test the effects of structural changes (account holder scenario), policy changes (settlement scenario) or changes in optimization routines (system scenario). A simulation run incorporates a combination of scenario settings as well as the input data. The properties of the scenarios are explained in more detail in the next section.

The account holder scenario defines the participants in the payment system. Properties of an account holder include such properties as intraday credit limits, potential debit caps and starting balances. This scenario answers the question: ‘Who’ are the system participants?

The settlement scenario defines the system’s settlement procedures. In this scenario one specifies the number and types of payment classes as well as the actions or settlement procedures for each payment class. Different payment classes may be settled using different settlement systems. The settings in the settlement scenario answer the question: ‘What’ happens at each point in time to the payments that are being processed?

The settings in the systems scenario reflect the properties of the systems used for settlement. Three types of settlement systems are available: real-time gross settlement (RTGS), time-designated net settlement (TDNS) and continuous net settlement (CNS). The properties of the systems can be set independently of the payment data or the other scenarios. The systems scenario answers the question: ‘How’ do the settlement procedures specified for the settlement scenario work in practice?
4.1.1 Account holder scenario

In the account holder scenario the properties of account holders participating in the RTGS and CNS systems are defined. The simulator does not impose a limit on the maximum number of account holders in the system, but as the number of account holders increases also the computational requirements are increased.

Properties of account holders include account limits and starting balances. A bank’s starting balance can for example be understood as its required reserves plus any excess reserves held at the central bank. The amount of liquidity available for the bank at the start of the settlement day is the sum of its starting balance plus its account credit limit. If no credit limit is set on its intraday overdrafts, the account holder has in effect unlimited liquidity during the day. Changes in the values of account limits in an RTGS system during a simulation day can also be pre-programmed.

Every account holder can participate in a CNS system. Account holders who are CNS participants have bilateral or multilateral debt limits against other participants. Two types of credit limits can be set, RTGS limits and net debt limits. If a payment settled in the CNS system exceeds the RTGS limit, it is settled in the RTGS system. The RTGS limit marks the upper bound for a debt relation in the system, beyond which positions are cleared using real-time gross settlement. The debt limits between individual banks may be set freely as long as the net limit is greater than the RTGS limit. These types of credit limits are used in the Finnish POPS settlement system.

4.1.2 Settlement scenario

In the settlement scenario the payment classes used in the simulations and the settlement procedures for each of the payment classes are defined. If some types of payments are considered more time-critical than others, payment classes can be given priorities. Each payment class then forms its own subqueue, and subqueues
with higher priority are settled before those with lower priority. If the priority of a payment class is set at 0, payments of this class are settled immediately. If the sending account holder does not have sufficient liquidity to settle a payment, the simulation is halted or the account holder’s credit limit is raised (eg in settlement of net positions of payments originating in netting systems).

Each payment class is assigned a set of settlement procedures. A settlement procedure has a starting time and a corresponding action. During the day any combination of the available settlement procedures may be used. If no settlement procedure is defined, the payments are not settled during that period. Procedures available are:

1. real-time gross settlement (RTGS)
2. continuous net settlement (CNS)
3. time designated net settlement (TDNS)
4. RTGS queuing
5. CNS queuing
6. postponed to next day
7. not settled

Payments that are put into RTGS or CNS queues are settled when the corresponding system opens, ie at the starting time for the respective settlement procedure. Payments postponed to the next day are added to the next day’s payment data with the time stamp 0:00.

If time designated net settlement is chosen as the settlement procedure for a payment class, a predefined TDNS system must be selected. In the TDNS system, the execution time for the net settlement, the type of settlement (bilateral or multilateral), the settlement agent and the netting algorithm used are defined. From the defined starting point on, the simulator collects payments into the net settlement and calculates and settles the net positions at the time point defined in the TDNS system settings. The net positions can be calculated on a multilateral or bilateral basis, and
the transfers can go through the books of a system account holder or the books of a
centralized clearing party (e.g., an automated clearing house). In the TDNS settings,
different courses of actions are available in case of a liquidity shortfall. If an account
holder cannot settle its net settlement obligations, the transfers could be queued, the
account holder could be automatically given the necessary liquidity, or the
simulation could be halted while liquidity is injected manually into the system.

4.1.3 Systems scenario

In the systems scenario the properties of the RTGS and CNS systems are defined.
These include any optimization methods such as queuing of payments, splitting of
payments or netting of queues.

Queuing of payments can be organized according to two different principles: 'first in,
first out' (FIFO) or 'Bypass FIFO'. In a FIFO queuing arrangement, payments put
earlier into the queue are settled earlier. If some payments are more time-critical than
others, payment classes may be given priorities. The priorities are defined in the
settlement scenario. Another type of queuing is FIFO with bypass arrangements. In
this type of queuing the first transfer in a queue initially has priority over subsequent
payments. If the bank does not have enough liquidity to settle the first payment
according to the FIFO rule, settlement of subsequent payments is tried. Payment
prioritization can be enabled or disabled in this scenario for both the RTGS system
and the CNS system.

The simulator offers the possibility of netting the queued transfers. Net settlement of
queued transfers can be used to solve a system gridlock. If every account holder has
a balance that is larger than its calculated net amount of queued incoming and
outgoing payments, the queues are cleared and the net positions are booked in the
participants' settlement accounts. In this scenario, one can set the time of the first
attempt at net settlement of queued transfers as well as the time interval between
subsequent attempts and the netting algorithm used.
Another way to make the RTGS system work more smoothly and to avoid gridlock is to split large payments into several smaller ones. The parameters relating to the splitting of payments in the RTGS system are set in this scenario. One can set any minimum value of payments for triggering payments splitting in the event of a liquidity shortfall. The value of payments generated by a splitting of the original transfer can be determined in two ways. In the first (equal) type of splitting, the payment is split into the minimum number of equal-sized payments such that each is smaller than the split limit. In the second (whole liquidity) type of splitting, the original payment is split in two so that the value of the first payment equals the amount of liquidity available to the bank and the value of the second is the value of the original payment minus the value of the first generated payment.

4.2 Components of the simulator

The technical implementation of features in the settlement system can substantially affect its efficiency. In this section a more technical description of the simulator is presented and in sections 4.2.1 to 4.2.3 the logic of the most important parts of the simulator is explained. The flow charts given are simplified presentations of the actual program, which show how behaviour identical to that in actual systems was achieved with the simulator.

The payment system is organized in the settlement simulator as depicted in figure 5, which presents the object model of the simulator. The scenarios drawn in the figure with dashed lines and marked A, B, C are respectively the systems, settlement and account holder scenario. A combination of scenarios selected at the start of a simulation run is referred to as a settlement structure.

The system object in the object model controls the other objects and their interaction according to the property settings. For example, as payments (Transfers or Netposition objects) are generated by the CNS or TDNS objects, they are settled in
the RTGS object and the balance property of the Accountholder object is changed. The logic of the settlement resides in the Paymentclasses object. Each payment class can be settled by any of the three methods (RTGS, CNS, and TDNS) or any combination of these during the day.

Figure 5. **Payment systems simulator object model**

The settlement structure always includes one RTGS system and may include one CNS system; zero or several TDNS systems can be included. The account holders of the CNS system are a subset of those of the RTGS system. An account holder must participate in the RTGS system in order to participate in the CNS system but not vice versa. Each account holder may have zero or several caps, depending on whether it is a CNS participant. Each account holder may also have zero or several changes in intraday credit limits during the simulation period. At least one payment class and
one corresponding settlement procedure must be defined. The simulator imposes no maximum numbers for these.

4.2.1 Simulation run

The simulator uses the 'next event timing' technique to determine the actions to be taken. The simulation time starts at 0:00, at which time the first payment to be settled is fetched from the database. Before the start of each one-minute period, the actions or settlement procedures for each payment class are updated. Also the objects in the system are checked to determine if there is any interaction between them. This is handled by the routine ‘system check’, which is explained later in more detail.

After checking the system for time-discrete events, the time stamp of the current payment is checked against the current time in the simulator. If the time stamp matches the current time, the payment is entered into the system and a new payment is fetched. When a payment is entered into the system, its payment class is checked against the current action of the payment class. With this information, the payment is processed using one of the seven possible actions\(^\text{14}\) as explained in section 4.1.2.

Payments are entered into the system as long as their time stamps match the simulation time. If the times do not match, the simulation time is advanced by one minute. This is repeated until a payment is found with a time stamp matching the simulation time. In each such loop, the settlement procedures for each payment class are updated and the system is checked for the existence of time-discrete events. This procedure is illustrated in figure 6.

\(^{14}\)These actions are: real-time gross settlement, secured net settlement, time designated net settlement, RTGS queued, CNS queued, postponed to next day, and not settled.
Figure 6. Overview of the simulation run

Fetch payment from database

Update settlement procedures

Check system

Simulation time = Simulation time + one minute

Time stamp of payment equals simulation time

Enter payment into system

Fetch new payment

More payments for the day

1 A shadowed box in the figures means that the procedure is explained in more detail later in this section.
4.2.2 System check

The system check routine handles the interoperation of the different settlement systems and the pre-programmed or system-generated time-discrete events. The continuous net settlement system and the real-time gross settlement system are checked as well. Queued payments in these systems may be settled as a result of liquidity changes caused by any other events occurring in the same one-minute period.

The system check routine is ordered as follows

1. pre-programmed changes in intraday credit limits
2. execution of net settlements
3. queues in the continuous net settlement system
4. netting of queues in the RTGS system
5. queues in the RTGS system.

4.2.3 RTGS system

If a payment is forwarded to the RTGS system, the sender’s credit limit is checked. If the account holder does not have unlimited credit and its liquidity is not sufficient to cover the payment, the payment is queued; otherwise it is settled. Account holders with unlimited credit might be the central bank itself or other governmental entities whose obligations are guaranteed by the central bank.
If payments splitting is used, the payment is split before it is queued, provided its value is above the specified split limit. The payment is split according to the type of splitting selected in the systems scenario. At the end of this procedure, regardless of whether the payment was settled or queued, the queue in the RTGS system is checked for any payments that can be settled. An overview of RTGS settlement is given in figure 7, and procedures for settling the queued transfers are depicted in figure 8.
At the start of the procedure in figure 8, queued payments are sorted according to priorities and system-entry times. Payment prioritization can be optionally suspended and the pure FIFO rule applied. After that, the first payment in the queue is fetched and the sender's status is checked. If the bank is closed in the simulator, i.e., it already has queued payments and lacks the liquidity for settling them, the next payment in the queue is fetched. This loop is continued until a payment is found whose sender has no prior queued payments. The value of the payment is then checked against the sender's liquidity. If the liquidity is sufficient, the payment is settled. Otherwise, the status of the sender is changed to closed and the next payment in the queue is fetched. If the payment is settled, the receiver is returned to the system and its status is set to open. These loops are repeated until all banks are closed or there are no more
payments in the queue. If all banks have the closed status, this means that all payments that can be settled by the banks with the available liquidity have been settled.

4.3 The simulations and data employed

The optimization methods are studied within an RTGS-with-queuing structure with 100 days of actual payment data. The purpose of these simulations is to study the effects of different optimization methods on liquidity needs and the formation of queues. The optimization methods tested are the netting of queues with two time intervals and two netting algorithms, and the splitting of payments with four different split limits. These are summarized in table 2. As each of the optimization methods was simulated with one hundred days and eleven levels of intraday credit limits, the total number of simulation runs was 9900.

<table>
<thead>
<tr>
<th>Table 2. Simulation runs</th>
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<tbody>
<tr>
<td>Account holder scenario</td>
</tr>
<tr>
<td>Systems scenario</td>
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<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Settlement scenario</td>
</tr>
<tr>
<td>Intraday credit limits</td>
</tr>
<tr>
<td>Simulation period</td>
</tr>
</tbody>
</table>

\textsuperscript{15} The TARGET (Trans-European Automated Real-time Gross settlement Express Transfer) system is a payment system composed of the national (Euro-based) RTGS systems of the EU-countries and the European Central Bank (ECB) payment mechanism.
The data used in the simulations was collected from the Bank of Finland’s current account system. The data includes all payments made in the Bank of Finland’s RTGS system between the period of 4. January and 21. May 1999. The time period holds altogether one hundred banking days. This section provides some basic statistics of the data.

The value and number breakdowns over different payment classes are summed up in Table 3. The Bank’s Payment Clearing is a netting system operated by the banks and where net balances are settled at the Bank of Finland twice each day, in the morning at 8:30 AM and in the afternoon at 3:45 PM. The clearing system handles customer payments between the banks such as credit transfers, recurrent payments, direct debits, bank card payments and automated teller machine (ATM) transactions. There are no plans at the present to change the settlement of these payments to use more gross settlement. The value of the net positions transferred between the banks in the BoF-RTGS was only 3% of the total value of transactions.

Money market transactions are usually large payments that relate to open market operations by the Bank of Finland and payments and to money market trading. These are the third largest group of payments in the system. POPS net transactions are related to the bilateral netting system, the POPS system, operated by the banks and introduced in 1998. Payments settled in this subsystem are interbank online express transfers and cheques. Payments exceeding pre-defined bilateral interbank limits are settled on gross basis in the BoF-RTGS.

Loro payments are markka-denominated cross-border payments between residents and non-residents or between non-residents in Finland. Loro payments have been settled on a gross basis from the beginning of October 1998 and by the end of year 1998 loro payments were the single largest group of payments. Since the introduction of the common currency the volume of these payments has been greatly reduced and they now account for 32% of the total number of payments and a mere 3% of the aggregate value.
Table 3. 

<table>
<thead>
<tr>
<th>Payment class</th>
<th>Daily average value, mill. €</th>
<th>Daily average number of payments</th>
<th>% of daily value</th>
<th>% of daily number</th>
<th>Average value of payment, mill. €</th>
<th>Largest value of payment, mill. €</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banks' payment clearing</td>
<td>461.8</td>
<td>107</td>
<td>3 %</td>
<td>6 %</td>
<td>4.3</td>
<td>496.0</td>
</tr>
<tr>
<td>Money market transactions</td>
<td>1 017.3</td>
<td>22</td>
<td>6 %</td>
<td>2 %</td>
<td>46.4</td>
<td>598.2</td>
</tr>
<tr>
<td>POPS net transactions</td>
<td>792.3</td>
<td>30</td>
<td>4 %</td>
<td>2 %</td>
<td>26.6</td>
<td>480.2</td>
</tr>
<tr>
<td>POPS gross transactions</td>
<td>321.9</td>
<td>44</td>
<td>2 %</td>
<td>2 %</td>
<td>7.4</td>
<td>100.0</td>
</tr>
<tr>
<td>Loro payments</td>
<td>501.9</td>
<td>580</td>
<td>3 %</td>
<td>32 %</td>
<td>0.9</td>
<td>706.9</td>
</tr>
<tr>
<td>Financial market transactions</td>
<td>2 098.3</td>
<td>113</td>
<td>11 %</td>
<td>6 %</td>
<td>18.6</td>
<td>2 388.3</td>
</tr>
<tr>
<td>Target transfers</td>
<td>12 594.4</td>
<td>803</td>
<td>69 %</td>
<td>45 %</td>
<td>15.7</td>
<td>6 000.0</td>
</tr>
<tr>
<td>Currency maintenance transactions</td>
<td>39.8</td>
<td>67</td>
<td>0 %</td>
<td>4 %</td>
<td>0.6</td>
<td>22.1</td>
</tr>
<tr>
<td>Foreign exchange trades</td>
<td>37.5</td>
<td>3</td>
<td>0 %</td>
<td>0 %</td>
<td>11.0</td>
<td>168.2</td>
</tr>
<tr>
<td>Other</td>
<td>399.4</td>
<td>22</td>
<td>2 %</td>
<td>1 %</td>
<td>18.5</td>
<td>1 000.0</td>
</tr>
<tr>
<td>Total</td>
<td>18 264.7</td>
<td>1 790</td>
<td>100 %</td>
<td>100 %</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Financial market transactions are the second largest category after TARGET transactions as measured by total value. TARGET transactions include transactions from and to other countries of the TARGET network. These payments are by far the largest category whether measured by value or number of payments with a daily average value of almost € 12.6 billion. The last two categories include payments related to the maintenance of the currency supply by the Bank of Finland and payments related to foreign exchange trading. The payment class 'other' includes among others interests paid on reserve requirements and payments related to postal giro accounts.

Table 4 summarizes the value distribution of all payments. The distribution is rather flat with few payments under € 1000 and few over € 100 million. The largest payments naturally impose the highest liquidity constraints, but only 16 payments during the period were over € 1 billion.
Table 4. Value distribution of transactions

<table>
<thead>
<tr>
<th>Value, mill. €</th>
<th>Number</th>
<th>Share, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>-&gt; 0,0001</td>
<td>6603</td>
<td>3,7 %</td>
</tr>
<tr>
<td>0,0001 -&gt; 0,001</td>
<td>17977</td>
<td>10,0 %</td>
</tr>
<tr>
<td>0,001 -&gt; 0,01</td>
<td>31018</td>
<td>17,2 %</td>
</tr>
<tr>
<td>0,01 -&gt; 0,1</td>
<td>37584</td>
<td>20,8 %</td>
</tr>
<tr>
<td>0,1 -&gt; 1</td>
<td>36364</td>
<td>20,1 %</td>
</tr>
<tr>
<td>1 -&gt; 10</td>
<td>27981</td>
<td>15,5 %</td>
</tr>
<tr>
<td>10 -&gt; 100</td>
<td>17107</td>
<td>9,5 %</td>
</tr>
<tr>
<td>100 -&gt; 1000</td>
<td>4373</td>
<td>2,4 %</td>
</tr>
<tr>
<td>1000 -&gt;</td>
<td>16</td>
<td>0,0 %</td>
</tr>
</tbody>
</table>

The value and number of payments on each day during the study period are depicted in Figure 9. The average number and value of daily transactions during the period were 1790 and € 18,265 million respectively.

Figure 9. Number and value of payments (daily observations, 4.1-21.5.1999)
The variation in the value of payment has been considerably larger than the variation in the number of payments. This can be traced to the infrequent very large payments. The largest payment during the period was € 6000 million. The sharp drops in the transaction volumes are due to holidays; Epiphany in January, Easter in April and Ascension Day in May.

Figure 10 illustrates the intraday distribution of the transactions. During periods of infrequent payment settlement the importance of incoming payments as a source for liquidity is diminished. In the Finnish payment settlement system the settlement of payments is rather stable at ten to twenty payments per minute after 9:00 AM. Banks have agreed to enter their outgoing loro payments into the system right after the opening of the system and this can be seen as a peak in the number and value of payments between 8:00 and 8:30 AM. The peaks between 17:00 PM and 19:00 PM are related to large valued TARGET transactions at the end of the day.

Figure 10. **Intraday distribution of transactions (10 minute interval average, 4.1-21.5.1999)**
5 Indicators used in the study

This chapter explains the calculation of liquidity bounds and the indicators used in this study for settlement delay and liquidity usage. All simulations were run with liquidity levels within these boundaries.

5.1 Calculation of boundaries for liquidity need

The behaviour of the liquidity position of a hypothetical bank in an RTGS system during a day is illustrated in figure 11. Within this context, the bank begins the day with a zero liquidity position and an unlimited credit extension. The incoming and outgoing transfers affect the bank’s liquidity throughout the day. As can be seen in the figure, the flow of payments during the day is quite uneven. The bank sends its payments at the start of the day, but its counterparties send their payments mostly at the end of the day. This results in an overall large liquidity need in relation to the value of payments settled in case all payments are to be settled immediately.

The end-of-day liquidity need, point B in the figure, represents the net amount of incoming and outgoing payments during the day. This point is the lower bound (LB) for a bank’s liquidity in an RTGS system with queuing. However, this lower bound holds only if none of the payments settled are time-critical and hence liquidity need not be available for settlement until the end of the day.\(^{16}\) The simulations of this study do not include payment prioritization and it is assumed that none of the payments settled are time-critical.

The upper bound for liquidity need is relevant if all payments are settled without queuing. In order to determine the upper bound for the liquidity need for each account holder in each payment settlement system, preliminary simulations were run.

\(^{16}\) In the Finnish payment settlement systems, net positions originating from net settlement systems must be settled immediately and POPS-RTGS payments and POPS buckets within an hour after entry into the system.
In these simulations, all account holders were assigned infinite intraday credit extensions to enable immediate settlement of all payments. An accountholder's minimum liquidity position during the day then represents the theoretical upper bound for its liquidity need (UB). This was calculated as the minimum of the cumulative net positions of incoming and outgoing payments at all points of time during the day. This amount is represented by point A in figure 11.

Figure 11.  
**Intraday liquidity usage by a hypothetical bank in an RTGS system**

Because queuing of payments takes place only between the lower and upper bounds, only liquidity levels between these bounds are of interest in this study. In the simulations, eleven different liquidity levels between the bounds were used. These levels are represented in figure 12 as points on the line ranging from a liquidity level of 0 per cent to 100 per cent.

The amount of liquidity available for any account holder $i$ is calculated as shown in equation 4. Liquidity available for each bank at a particular liquidity level is the sum of the lower bound and the corresponding liquidity level multiplied by the difference between the bounds. The lower bound for liquidity need is the 0 per cent liquidity level and the upper bound the 100 per cent.
Equation 4: Liquidity available, \( LA_i \), for account holder \( i \) at a given liquidity level, \( LL \) (\( LB = \) lower bound, \( UB = \) upper bound)

In calculating system liquidity need, the system upper bound, and system lower bound; the corresponding values for each account holder are simply added up. It should be noted that the liquidity must be optimally distributed in order for the system bounds to hold. If some banks have below-optimal liquidity and others above-optimal, the system liquidity might equal that of the calculated bound and yet settlement behaviour could differ. The curve in figure 12 shows the points where the liquidity is optimally distributed across system participants. A reduction of any participant’s liquidity would cause extra delay in settlement.

Figure 12. *Relationship between a bank’s settlement delay and liquidity usage in a payment system with various liquidity levels*
5.2 Settlement delay indicator

The indicator used for settlement delay in this study is called $\rho$. The values of $\rho$ range from zero to one and it is calculated for each account holder as shown in equation 5. The numerator in equation 5 represents the sum of queues, i.e., the sum of the values of queued payments over each minute of the day. The denominator represents the sum of the cumulative values of outgoing payments over each minute of the day, and $\rho$ is the ratio of the two.

\[
\rho = \frac{\sum_{i=1}^{T} Q_i}{\sum_{i=1}^{T} \sum_{j=1}^{T} V_i}
\]

Equation 5: Indicator of settlement delay, $\rho$, for an account holder ($Q_i =$ value of queue at time $i$, $V_i =$ value of outgoing payments at time $i$)

If a bank does not have any liquidity at the start of the day and does not receive any in the form of incoming payments, all transfers remain queued and are not settled at all or only at the end of the day. In this case, $\rho$ equals one. On the other hand, if the bank has an abundance of liquidity, all payments get settled immediately and $\rho$ is zero.

The calculation of $\rho$ is illustrated in figure 13. The height of the curve defining the dark grey area (A) represents the total value of a bank’s queued payments at each minute. The light grey area (B) represents the bank’s cumulative value of all outgoing payments settled at each minute during the day. The settlement delay indicator, $\rho$, is the ratio of A to B.

In calculating the system $\rho$, the numerator and denominator in equation 5 are summed up over all account holders in the system. The system $\rho$ is thus a weighted
average of individual account holders' ρs, where the weights are corresponding shares of the account holders in the total value of payments.

By using such an indicator, the settlement delay in various systems can be measured in a standardized manner. ρ takes into account the value and queuing times of delayed transfers as well as their importance in the total value of payments.

Figure 13. **Settlement delay indicator ρ = A/B**

![Diagram showing settlement delay indicator](image)
5.3 Liquidity usage indicator

Banks operating in a European-type RTGS system must fully collateralize their daily overdrafts. The central bank then converts the collateral into central bank money for the settlement of payments during the day. These securities are tied up as collateral and have an opportunity cost because they are no longer available for trading or other purposes during the day.

In situations where credit limits are seldom revised and so remain constant over longer periods of time, a bank’s liquidity usage could be understood as the sum of liquidity available to the bank at the start of the day plus available intraday credit limits. This is the amount of money that is excluded from other purposes and is thus associated with an opportunity cost.

In situations where the banks can freely alter their intraday credit limits during the day, liquidity usage should be calculated differently. As the banks are able to raise their intraday credit limits during the day for the settlement of time-critical transfers, they can also withdraw collateral and lower their limits if the collateral or liquidity is needed elsewhere. In the Finnish BoF-RTGS system, credit limits can be dynamically adjusted during the day via the automatic collateral management service of Finnish Central Securities Depository Ltd.

We can further differentiate between situations where interest is calculated on a daily basis and situations where the interest period is shorter, eg hourly or continuously. In the first case, it is reasonable to use the peak liquidity usage during the day as the bank’s liquidity usage, as this is the amount needed for the whole day. In the latter case, a good indicator of the liquidity usage would take the time aspect into account. Liquidity usage could be calculated continuously for each time unit of cost during the day.

In this study, liquidity usage is calculated as the sum of the peak usage of intraday limits plus the peak usage of the starting liquidity position. The corresponding
Indicator, denoted \( \pi \), is calculated for each bank as the ratio of its liquidity usage to the total value of its outgoing payments during the day. \( \pi \) ranges from zero to one. A \( \pi \) of zero means that there is no need for liquidity from outside the system, and if \( \pi \) equals one, liquidity is needed in the amount of the gross value of outgoing payments. \( \pi \) can also be understood as the reciprocal of the turnover ratio.

\[
(6) \quad \pi = \frac{LU}{\sum_{t=0}^{T} V_t}
\]

Equation 6: Liquidity usage indicator, \( \pi \), for an account holder

\(LU = \) peak use of starting liquidity position + peak use of credits extended, \(V_t = \) value of payments sent at time \(t\)

In calculating the system \( \pi \), the liquidity usages of individual account holders are summed and divided by the total value of payments during the day. This is equivalent to the weighted average of the banks' \( \pi_s \), where the weights are the banks' respective shares of the total value of payments.
6 Results from the simulations

6.1 Queuing of payments

In an RTGS system with a queuing facility banks that are willing to accept more delay in their payments can reduce their liquidity usage along a trade-off curve. The system level trade-off curve in which the participants’ trade-off curves are summed up is shown as segment CB in figure 1. Liquidity must remain at least at the lower bound of liquidity i.e. point B, if all payments during the day are to be settled. Banks can theoretically choose any point on their curve segment BC, according to their preferences and perceptions on the relative costs of liquidity and delay. If a bank perceives the cost of liquidity high relative to that of settlement delay, it chooses a point near B and vice versa.

Figure 14. Relationship between settlement delay ($\rho$) and liquidity usage ($\pi$) in RTGS-with-queuing structure
The range at which liquidity can be substituted for settlement delay is rather wide in our case, on the average 32% of the daily value of payments. The curve is convex and the slope of the curve is above -1 until the 70% liquidity level and after that between -0.5 and 0.6. Until the 70% liquidity level an increase in liquidity usage is compensated by a larger relative reduction in settlement delay after which the trade-off is diminishing.

Table 5. **System liquidity need (\(\pi\)) and settlement delay (\(\rho\)) in the RTGS-with-queuing structure, selected liquidity levels**

<table>
<thead>
<tr>
<th>Liquidity level, %</th>
<th>Average, (\pi), %</th>
<th>Maximum, (\pi), %</th>
<th>Minimum, (\pi), %</th>
<th>Average, (\rho), %</th>
<th>Maximum, (\rho), %</th>
<th>Minimum, (\rho), %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5 %</td>
<td>28 %</td>
<td>0 %</td>
<td>38 %</td>
<td>85 %</td>
<td>13 %</td>
</tr>
<tr>
<td>10</td>
<td>8 %</td>
<td>29 %</td>
<td>2 %</td>
<td>32 %</td>
<td>85 %</td>
<td>7 %</td>
</tr>
<tr>
<td>20</td>
<td>11 %</td>
<td>30 %</td>
<td>5 %</td>
<td>26 %</td>
<td>85 %</td>
<td>5 %</td>
</tr>
<tr>
<td>30</td>
<td>15 %</td>
<td>32 %</td>
<td>7 %</td>
<td>21 %</td>
<td>85 %</td>
<td>4 %</td>
</tr>
<tr>
<td>40</td>
<td>18 %</td>
<td>35 %</td>
<td>9 %</td>
<td>16 %</td>
<td>78 %</td>
<td>2 %</td>
</tr>
<tr>
<td>50</td>
<td>21 %</td>
<td>42 %</td>
<td>12 %</td>
<td>12 %</td>
<td>71 %</td>
<td>2 %</td>
</tr>
<tr>
<td>60</td>
<td>24 %</td>
<td>49 %</td>
<td>14 %</td>
<td>8 %</td>
<td>62 %</td>
<td>1 %</td>
</tr>
<tr>
<td>70</td>
<td>27 %</td>
<td>57 %</td>
<td>16 %</td>
<td>5 %</td>
<td>35 %</td>
<td>1 %</td>
</tr>
<tr>
<td>80</td>
<td>31 %</td>
<td>65 %</td>
<td>18 %</td>
<td>3 %</td>
<td>24 %</td>
<td>0 %</td>
</tr>
<tr>
<td>90</td>
<td>34 %</td>
<td>73 %</td>
<td>20 %</td>
<td>2 %</td>
<td>23 %</td>
<td>0 %</td>
</tr>
<tr>
<td>100</td>
<td>37 %</td>
<td>81 %</td>
<td>22 %</td>
<td>0 %</td>
<td>0 %</td>
<td>0 %</td>
</tr>
</tbody>
</table>

The minimum and maximum liquidity usage and delay during the 100-day simulation period are shown in table 5. When the RTGS system was operating on the upper bound of liquidity or when no centrally managed queuing was facilitated, the system liquidity usage was on the average 37% of the total value of payments. In the simulations liquidity usage ranged between 22% on the best day and 81% on the worst day. On the upper bound the liquidity need of the system depends solely on the order of payments arriving the system. The more imbalanced the payment flows between the participants are the more liquidity is required. On the best day almost all external liquidity could be removed from the system and the participants were able to settle their payments from liquidity received as incoming payments. At the upper bound of liquidity naturally no queuing takes place but as liquidity is reduced.
more delays in payments are experienced. The difference between the minimum and maximum daily delay on each level of liquidity is very wide. Already at relatively high levels of liquidity substantial queuing took place although the average daily delay remained relatively low. For example at the 60%-level of liquidity the average \( \rho \) amounted to 8% while the maximum \( \rho \) was 62%. As \( \rho \) can be interpreted as the share of payments that are settled at the end of the day instead of immediately, at low levels of liquidity the RTGS system actually resembles on some days an end-of-day net settlement system. On the worst day the equivalent share of payments settled at the end of the day equalled 85% on liquidity levels between 0% and 30%.

6.2  Splitting of payments

Altogether four splitting limits were simulated. The splitting levels, the equivalent minimum values for payments to be split and the actual number of payments split are shown in table 6. In the type of splitting used in this study, the original payment is split into equal-size payments so that the value of a payment is less than or equal to the split limit. The actual number of payments split depends heavily on the amount of available liquidity. At the upper bound of liquidity no payments had to be split as no queuing took place and at the lower bound of liquidity 25% to 50% of the payments eligible for splitting were actually split, depending on the limit above which the payments were split.

Table 6.  

<table>
<thead>
<tr>
<th>Upper percentile split, %</th>
<th>Minimum value for payment split, mill. €</th>
<th>Number of payments eligible for splitting</th>
<th>Number of payments split at lower bound of liquidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>&gt;16.3</td>
<td>17 906</td>
<td>9605</td>
</tr>
<tr>
<td>5</td>
<td>&gt;45.0</td>
<td>8948</td>
<td>4380</td>
</tr>
<tr>
<td>1</td>
<td>&gt;200.0</td>
<td>1733</td>
<td>660</td>
</tr>
<tr>
<td>0.1</td>
<td>&gt;1000.0</td>
<td>16</td>
<td>4</td>
</tr>
</tbody>
</table>
The relationship between liquidity usage and settlement delay for each of the split limits is shown in figure 15. In general, settlement delay can be reduced at all levels of liquidity by splitting large payments into several smaller ones. Splitting of the largest 10 per cent of the payments is naturally the most effective way to reduce settlement delay, albeit splitting the top 5 per cent is almost as effective. The absolute effects of payment splitting are much more evident at low levels of liquidity as the queuing of payments is more frequent and the optimization of liquidity becomes a more important issue.

Figure 15. Effects of payment splitting on system liquidity usage ($\pi$) and settlement delay ($\rho$)

The change in settlement delay as shown in table 7 refers to an average percentage change in settlement delay over all liquidity levels, in response to a change in the system. The reduction in settlement delay as a result of splitting the top 10 per cent of payments, compared to the top 5 per cent, was only 1.5 per cent on average. Splitting the top 5 per cent reduced settlement delay by 4.8 per cent more, compared
to splitting the top 1 per cent, and the shift from 0.1 per cent to 1 percent reduced settlement delay by 5.3 per cent. This suggests that the largest 5 per cent of the payments cause most of the liquidity scarcity and hence most of the settlement delays. The gains from splitting more payments are of diminishing nature.

Table 7. **Relative changes in settlement delay ($\rho$) with selected split limits**

<table>
<thead>
<tr>
<th>SHIFT BETWEEN SYSTEMS</th>
<th>CHANGE IN SETTLEMENT DELAY, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>no splitting (1) -&gt; split 0.1% (2)</td>
<td>-0.8</td>
</tr>
<tr>
<td>split 0.1% (2) -&gt; split 1.0% (3)</td>
<td>-5.3</td>
</tr>
<tr>
<td>split 1.0% (3) -&gt; split 5.0% (4)</td>
<td>-4.8</td>
</tr>
<tr>
<td>split 5.0% (4) -&gt; split 10.0% (5)</td>
<td>-1.5</td>
</tr>
</tbody>
</table>

The change in queuing resulting from the splitting of payments is summed up in figure 16. The liquidity level axis represents the different levels of available liquidity between the upper and lower bounds. In general it can be said that payments splitting reduced settlement delay significantly at all liquidity levels besides the 100 %-level at which no queuing takes place, up to 10-12 per cent on low levels of liquidity and with 5 or 10 per cent of payments eligible for splitting.
During the day the settlement of payments may be temporarily halted because of actual gridlocks or illiquidity on the part of one or more participants. Splitting helps only in preventing gridlocks and has no effect on illiquidity situations.

The effect of payment splitting on gridlocks is shown in figure 17. Most of the gridlocks occurred in the simulations at the zero liquidity level, with average gridlock duration of 4.2 minutes per day. In an RTGS-with-queuing system without optimization routines, gridlocks occurred at all tested levels of available liquidity. However, for liquidity levels above the lower bound of liquidity, the average daily total duration of gridlocks was short. The peak in gridlock duration at the 60%-liquidity level suggests that the random variation in gridlocks is substantial and does not depend wholly on the amount of liquidity available to the participants. Payments with very high values in comparison to the aggregate value of payments processed in the system can create persistent gridlocks, even when the participants are operating on high levels of liquidity in relation to their whole payment flow.
Splitting the largest 10 per cent of the payments was the most effective way of reducing gridlock duration. Gridlocks occurred at all split limits only when all system participants were operating at minimum possible liquidity for all payments to get settled, i.e., at the zero level of liquidity. The splitting of the top 5 per cent of payments was almost as effective, with gridlocks occurring only at the two lowest liquidity levels. Splitting only the largest payments (top 0.1 per cent of payments) seemed to reduce gridlocks only marginally.

Figure 18 illustrates the worst gridlock days. As one can see from the figure, there is a significant difference in the effects of splitting depending on whether the top 1 per cent or 5 per cent of payments are split. In the latter case, the peak duration of daily gridlocks was significantly shorter. This suggests that the largest 5 per cent of payments cause most of the gridlocks so that gridlocks can be prevented by splitting these payments.
In the simulations over one fourth of the days on which no optimization routine was used ended in gridlock when operating on the lower bound of liquidity. This means that, without optimization routines, liquidity equal to the liquidity used by a net settlement system with end-of-day net settlement was not sufficient. In the simulations these gridlocks were solved by executing a net settlement on the remaining queued payments. This clearly provides evidence of the need for optimization routines in RTGS systems.
6.3 Netting of queued payments

The netting of queued payments affects both liquidity usage and settlement delay. It reduces liquidity usage, since the net position of payments is always, by definition, equal to or is less than the liquidity need for settling payments on a gross basis. Netting of queues reduces settlement delay by solving gridlocks that prevent the settlement of payments even when liquidity is sufficient.

Figure 19. Effect of netting of queues on system liquidity usage (π) and settlement delay (ρ)

As can be seen from figure 19, the netting of queues is effective in reducing settlement delay only for the higher liquidity levels and even then only with minor effect. Curves 1, 2 and 3 and curves 4 and 5 in the figure representing systems with different netting intervals appear to coincide, but there are small differences, as becomes clear in figure 20. The effects of the full netting algorithm with bot 5 and
20 minute intervals are very close each other and seem to work better at higher levels of liquidity where there is a greater chance that all participants are liquid and the net settlement can be executed. Partial algorithms seem to work best at lower levels of liquidity, and also with this algorithm the choice of the netting interval had less effect. The delay was reduced by the full netting algorithm between 0 and 1 percent and by the partial algorithm between 2 and 8 per cent, depending on liquidity level and netting interval.

Figure 20. **Change in system settlement delay (\( \rho \)) due to use of netting of queues**

These results mean firstly that the netting of queues is not a very effective way of reducing settlement delay. Secondly, the banks must have enough liquidity in order to make netting of queues as effective as possible if not partial algorithms are used. Thirdly, the small difference between the effects of different time intervals suggests that in the payment data used the payments flows are too sparse, ie there are not
enough new transactions entered into the system to make five-minute time-intervals more effective than the 20-minute interval.

Figure 21. Effect of netting of queues on average daily gridlock duration as a function of liquidity

Figure 21 clearly shows that the netting of queues is a very effective method of reducing the time that the system is gridlocked (gridlock duration). In full netting of queues every 20 minutes the reduction in gridlocks amounted on the average to 57% and was at its highest on middle and high levels of liquidity. If the netting was executed every 5 minutes the reduction averaged to 86% and the level of liquidity had less effect. The use of the partial netting algorithm reduced gridlocks still further. At the 20-minute netting interval the average reduction was 92% and at the 5-minute interval 96%. It should however be noted that there were very few gridlocks on average.
On the worst days as illustrated in figure 22, the peak daily gridlock duration was 10 minutes over one hour for a system with no optimization routines. In this case the effect of the netting of queues is significant and quite similar regardless of liquidity level. Both full and partial netting reduced the maximum daily time the system was gridlocked remarkably. The resulting total duration of gridlocks was reduced approximately to the time interval between the nettings. In the worst case also the difference between the effects of different time-intervals is not very significant. This is quite natural because on the worst gridlock days, gridlocks were longer and more frequent.
Conclusions

One of the main findings of the study is that real-time gross settlement systems can operate with the same amount of liquidity as end-of-day netting systems with substantially increased speed in payment settlement. Although heavy queuing occurred on some days, even during the worst day settlement delay was reduced by 15%. The average reduction in settlement delay equalled 62%. According to the simulations the relationship between liquidity need and settlement delay in queuing systems is slightly convex to the origin meaning that the delay of settlement increases at a faster rate at low levels than at high levels of liquidity. On the average the banking sector's extra liquidity need in an RTGS system without queuing, compared to a system based on end-of-day net settlement or a system based on RTGS and operating with minimum possible liquidity, was found to be approximately 32% of the total value of daily payments.

The splitting of payments was found to be a more effective method for reducing settlement delay than the netting of queues. This is due to the fact that payment splitting works bilaterally between participants and thus does not require that all banks are liquid, as does the complete netting of queues. By splitting payments into several smaller ones and transferring the cover of these subpayments, a part of the cover is earlier available to the receivers of the queued payments to settle some of their payments. Payment splitting also makes more efficient use of available liquidity since the maximum amount of idle liquidity for a bank with queued payments is equal to the limit to which the payments are split. If netting of queued payments is chosen as the sole optimization method, partial algorithms were found to be more preferable. Partial netting algorithms work bilaterally between participants and these were found to be more efficient than full netting of queued transfers.

The risk of gridlocks was found to be rather modest. When the system was operating on the lower bound of liquidity the average daily gridlock duration was approximately 4 minutes per day. On higher liquidity levels it ranged between 1 and 3 minutes. Worst gridlock days occurred rather surprisingly when the system was
operating on higher levels of liquidity. When more liquidity was available, more situations were classified as gridlocks than illiquidity situations. With no optimization methods the peak daily gridlock duration equalled 70 minutes at 60% and 90% liquidity levels. For resolving gridlock situations, the netting of queues seemed to be more effective than payment splitting, especially at low levels of liquidity. The splitting of payments with a sufficiently low split limit (top 5 per cent of payments split) seemed to prevent the formation of gridlocks in the first place at higher levels of liquidity. The splitting of payments did not completely prevent the formation of gridlocks, whereas the netting of queues solves a gridlock immediately when it is executed. Some gridlocks occurred on the lowest levels of liquidity in spite of payment splitting because the split limits used in this study were not small enough to enable the use of all available liquidity.

The main limitation of the results is the exogenous character of the payment flow. If the features of the settlement system are changed as drastically as in our models there it is likely that it will affect customer and system participant behaviour, which in turn will affect the payment flow. The data used in the study was considered exogenously defined. Also variations over time in the payment flow can lead to different results in different time periods. The properties of the payment flow depend heavily on market conventions and customer behaviour. However, in spite the absolute amounts of delay and liquidity usage might vary when other payment data is used, the relative efficiency of the optimization methods should stay the same.

This study concentrated on the settlement and system scenarios of the simulator in assessing liquidity needs and corresponding settlement delays, but there are other factors that affect banks' liquidity needs. In this study the banking structure and payment characteristics were kept the same. It might be useful to pursue further study of the effects of different banking structures. The liquidity needs of a system with equal-size banks might differ from a system with banks of differing sizes but with the same total value of payments. In this study also the daily value distribution of the payment data was approximately the same over the 100-day period. With a different structure of small and large payments, the relationship between liquidity
need and settlement delay might differ substantially. The optimization methods tested were the splitting of payments and netting of queues. Further studies could be done on payment splitting that uses all available liquidity or more efficient netting algorithms. Also the effects of different queuing arrangements and algorithms not based on the FIFO principle might provide interesting topics for study. Risk considerations were not addressed in this study although the simulator can simulate bank failures and settlement delays. One could assess eg the systemic risk inherent in the Finnish payment system or other systems. Although cost functions of payment system, especially delay costs, costs associated with settlement risk and to some extent the liquidity costs are difficult to measure, estimation of these and the comparison of settlement systems in terms of total cost would surely be an interesting topic for further research.
References


Appendix 1: The Simulator

1 Reporting of the simulations

The payment systems simulator produces two types of reports: database reports generated at the end of each simulation run and reports that are available during running time. During a simulation run, the following performance statistics are updated for each account holder and for each settlement system simulated:

1. individual transfers and their handling procedures
2. the history of processed payments and their handling procedures
3. the balance and overall liquidity position of each account holder
4. total number and value of queued payments for each account holder
5. individual queued payments at each point of time.

For time designated net settlement systems, the net positions for each account holder are also updated.

The simulator produces two types of database reports for each simulation run. For each day simulated, a separate database report ('output') is produced. For each simulation run, which may consist of several days, another database report ('report') is produced. In the latter database the most important figures and aggregate information calculated from the first database is saved. The databases used and created by the simulator are illustrated in figure 23.

The variables reported by the simulator are summarized in table 8. The scope of the variable reported is denoted in table 8 as follows:

a) for each account holder if the variable is reported for each individual account holder,

For each transaction if the variable is reported for each individual payment settled or left unsettled by the simulator or
d) for each day if the results are aggregated only on a daily basis.

Figure 23  Databases used and created by the simulator

Not all variables are calculated for each of the three different settlement systems. The systems column in table 1 shows the settlement systems for which the variable is reported as follows:

r) for the real-time gross settlement system

c) for the continuous net settlement system or

t) for time designated net settlement systems.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Scope</th>
<th>Description</th>
<th>Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>After each transaction</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time stamp</td>
<td>a</td>
<td>Time of transaction</td>
<td>r,c</td>
</tr>
<tr>
<td>Balance</td>
<td>a</td>
<td>Balance of settlement account</td>
<td>r,c</td>
</tr>
<tr>
<td>Liquidity</td>
<td>a</td>
<td>(Starting balance limit) – Balance</td>
<td>r,c</td>
</tr>
<tr>
<td>Queue value (sum)</td>
<td>a</td>
<td>Total value of queued payments</td>
<td>r,c</td>
</tr>
<tr>
<td>Payments queued</td>
<td>a</td>
<td>Number of queued payments</td>
<td>r,c</td>
</tr>
<tr>
<td>Payments sent (cumulative)</td>
<td>a</td>
<td>Cumulative sum of payments sent</td>
<td>r,c</td>
</tr>
<tr>
<td>RTGS/CNS limits</td>
<td>a</td>
<td>Current RTGS or CNS limits</td>
<td>r,c</td>
</tr>
<tr>
<td><strong>For each payment settled</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identification number</td>
<td>t</td>
<td>Ordinal number of entry into system</td>
<td>r,c,t</td>
</tr>
<tr>
<td>Settlement number</td>
<td>t</td>
<td>Ordinal number of settlement</td>
<td>r,c,t</td>
</tr>
<tr>
<td>Entry time</td>
<td>t</td>
<td>Time when payment was entered into system</td>
<td>r,c,t</td>
</tr>
<tr>
<td>Value</td>
<td>t</td>
<td>Value of the payment, mill.</td>
<td>r,c,t</td>
</tr>
<tr>
<td>Receiver ID</td>
<td>t</td>
<td>ID of receiving account holder</td>
<td>r,c,t</td>
</tr>
<tr>
<td>Sender ID</td>
<td>t</td>
<td>ID of sending account holder</td>
<td>r,c,t</td>
</tr>
<tr>
<td>Priority</td>
<td>t</td>
<td>Priority of payment</td>
<td>r,c,t</td>
</tr>
<tr>
<td>Settlement time</td>
<td>t</td>
<td>Time when payment was settled</td>
<td>r,c,t</td>
</tr>
<tr>
<td>Settlement type ID</td>
<td>t</td>
<td>ID of the settlement system used for settlement</td>
<td>r,c,t</td>
</tr>
<tr>
<td>Time queuing</td>
<td>t</td>
<td>Queuing time for a payment: ie settlement time minus entry time</td>
<td>r,c</td>
</tr>
<tr>
<td><strong>For each minute during the day</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Balance (low)</td>
<td>a</td>
<td>Lowest value of balance</td>
<td>r,c</td>
</tr>
<tr>
<td>Limit usage (peak)</td>
<td>a</td>
<td>Percentage of limits used, ie -</td>
<td>r</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[Balance]/[Limit] if [Balance]&lt;0 and 0 if [Balance]&gt;0</td>
<td></td>
</tr>
<tr>
<td>Value of queued payments</td>
<td>a</td>
<td>Value of queued payments at end of each minute</td>
<td>r,c</td>
</tr>
<tr>
<td>Queued payments</td>
<td>a</td>
<td>Number of queued payments at the end of each minute</td>
<td>r,c</td>
</tr>
<tr>
<td>Variable</td>
<td>Scope</td>
<td>Description</td>
<td>Systems</td>
</tr>
<tr>
<td>-----------------------------------------</td>
<td>-------</td>
<td>-----------------------------------------------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>Value of queued payments</td>
<td>a</td>
<td>Total value of queued payments at each minute</td>
<td>r</td>
</tr>
<tr>
<td>Queued payments</td>
<td>a</td>
<td>Number of queued payments at each minute</td>
<td>r</td>
</tr>
<tr>
<td>Cumulated value of queued payments</td>
<td>a</td>
<td>Value of queued payments cumulated over time</td>
<td>r</td>
</tr>
<tr>
<td>Cumulated queued payments</td>
<td>a</td>
<td>Queued payments cumulated over time</td>
<td>r</td>
</tr>
<tr>
<td>For each run</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value of queue (avg, peak)</td>
<td>a</td>
<td>Average/peak value of queue at each minute</td>
<td>r</td>
</tr>
<tr>
<td>Queued payments (avg, peak)</td>
<td>a</td>
<td>Average/peak number of queued payments at each minute</td>
<td>r</td>
</tr>
<tr>
<td>Individual queuing time (avg, peak)</td>
<td>a</td>
<td>Average/peak time period during which individual payments are queued</td>
<td>r</td>
</tr>
<tr>
<td>Value of individual queued payments</td>
<td>a</td>
<td>Average/peak value of individual queued payments</td>
<td>r</td>
</tr>
<tr>
<td>Balance (avg, peak, low, st dev)</td>
<td>a</td>
<td>Average/peak/low/standard deviation of intra-minute minimum balances</td>
<td>r</td>
</tr>
<tr>
<td>Liquidity (low)</td>
<td>a</td>
<td>The lowest liquidity position during the day</td>
<td>r</td>
</tr>
<tr>
<td>Credit limit (low, peak)</td>
<td>a</td>
<td>The maximum value of intraday credit limit</td>
<td>r</td>
</tr>
<tr>
<td>Value of sent payments</td>
<td>a</td>
<td>Total value of payments sent</td>
<td>r,c,t</td>
</tr>
<tr>
<td>Payments sent</td>
<td>a</td>
<td>Number of payments sent</td>
<td>r,c,t</td>
</tr>
<tr>
<td>Queue %</td>
<td>a</td>
<td>Calculated as value of queue (peak)/value of sent payments</td>
<td>r</td>
</tr>
<tr>
<td>π</td>
<td>a</td>
<td>Represents degree of liquidity usage</td>
<td>r</td>
</tr>
<tr>
<td>ρ</td>
<td>a</td>
<td>Represents degree of settlement delay</td>
<td>r</td>
</tr>
<tr>
<td>Number of CNS transfers</td>
<td>a</td>
<td>Total number of CNS transfers during the day</td>
<td>c</td>
</tr>
<tr>
<td>Value of CNS transfers (tot, avg)</td>
<td>a</td>
<td>Total/average value of CNS transfers during the day</td>
<td>c</td>
</tr>
<tr>
<td>Variable</td>
<td>Scope</td>
<td>Description</td>
<td>Systems</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>-------</td>
<td>-----------------------------------------------------------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>Queuing time (avg, peak)</td>
<td>a</td>
<td>Average/peak time period during which payments are queued</td>
<td>r,c</td>
</tr>
<tr>
<td>Daily number of queued payments</td>
<td>a</td>
<td>Total number of payments queued during the day</td>
<td>r,c</td>
</tr>
<tr>
<td>Gridlock duration</td>
<td>d</td>
<td>Total number of minutes system was gridlocked during the day</td>
<td>r</td>
</tr>
<tr>
<td>End-of-day gridlock</td>
<td>d</td>
<td>A Boolean variable indicating weather system was gridlocked at end of day</td>
<td>r</td>
</tr>
<tr>
<td>Balance (start, end)</td>
<td>a</td>
<td>Day’s starting/ending balance</td>
<td>r</td>
</tr>
<tr>
<td>Run ID</td>
<td>d</td>
<td>Identification number of the simulation run</td>
<td></td>
</tr>
<tr>
<td>Data ID</td>
<td>d</td>
<td>Payment data used in current run</td>
<td></td>
</tr>
<tr>
<td>Limit used</td>
<td>d</td>
<td>Size of limits used in current simulation run</td>
<td></td>
</tr>
<tr>
<td>Settlement scenario ID</td>
<td>d</td>
<td>ID of settlement scenario used</td>
<td></td>
</tr>
<tr>
<td>System scenario ID</td>
<td>d</td>
<td>ID of system scenario used</td>
<td></td>
</tr>
<tr>
<td>Account holder scenario ID</td>
<td>d</td>
<td>ID of account holder scenario used</td>
<td></td>
</tr>
<tr>
<td>Liquidity usage</td>
<td>d</td>
<td>Liquidity used by the whole system</td>
<td></td>
</tr>
<tr>
<td>System value of sent payments</td>
<td>d</td>
<td>Total value of payments sent by the whole system</td>
<td></td>
</tr>
</tbody>
</table>

For each payment datum used

| Daily value of sent payments           | a     | Average/peak/low/standard deviation/total value of payments sent during the day |
| (avg, peak, low, st dev, tot)         |       |                                                                               |
| Number of sent payments               | a     | Total number of payments sent                                                 |
| Theoretical upper liquidity bound (avg)| a     | Average of theoretical upper bounds for day’s liquidity need                  |
| Theoretical lower liquidity bound (avg)| a     | Average of theoretical lower bounds for day’s liquidity need                  |

For each series of runs

<p>| Number of daily sent payments (avg, tot) | a     | Average/total number of payments sent during the simulation period |
| Std deviations of daily value of        | a     | Average standard deviation of daily                                        |</p>
<table>
<thead>
<tr>
<th>Variable</th>
<th>Scope</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>sent payments (avg)</td>
<td></td>
<td>values of payments sent during the simulation period</td>
</tr>
<tr>
<td>Total value of sent payments</td>
<td>a</td>
<td>Average/peak/low/total value of payments sent during the simulation period</td>
</tr>
<tr>
<td>(avg, peak, low, tot)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2 Hardware and software requirements

Computer/ Processor: PC with a Pentium processor (Pentium II recommended) or any Alpha processor running Microsoft Windows NT Workstation.

Memory: 64 MB of RAM

Hard Disk: Installation: 5 MB
Output databases: 1 to 4 MB for 1000 payments of input data (depending on settlement scenario used)
Report database: 2–4 MB per 100 days

Drive: CD-ROM drive

Operating System: Microsoft Windows 95 operating system, Microsoft Windows NT Workstation operating system version 4.0

Software requirements: Microsoft Access 97 or compatible
Simulator screenshots

Figure 24  View of simulation settings

Figure 25  View of account holder scenario: RTGS system participants
Figure 26  View of the account holder scenario: pre-programmed changes in intraday credit limits

Figure 27  View of account holder scenario: CNS credit limits
Figure 28 View of settlement scenario: payment classes

Figure 29 View of settlement scenario: settlement of payments
Figure 30  
View of systems scenario

Figure 31  
View of net settlement settings
Figure 32  Run-time view of simulator: RTGS system

Figure 33  Run-time view of simulator: CNS system
Figure 34  Run-time view of simulator: TDNS system

---

**Processed Payments**

<table>
<thead>
<tr>
<th>ID</th>
<th>Time</th>
<th>Value</th>
<th>Sender</th>
<th>Receiver</th>
<th>Payment class</th>
<th>Handling procedure</th>
<th>Set into Net Settlement</th>
</tr>
</thead>
<tbody>
<tr>
<td>428</td>
<td>11:38:00</td>
<td>0.001</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td></td>
<td></td>
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</tbody>
</table>

**Payment class**

Set into Net Settlement

---

**Multilateral Net Positions**

<table>
<thead>
<tr>
<th>Bank</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP</td>
<td>250,027</td>
</tr>
<tr>
<td>MERITA</td>
<td>-1915,611</td>
</tr>
<tr>
<td>LEONIA</td>
<td>535,050</td>
</tr>
<tr>
<td>OIKO</td>
<td>-93,425</td>
</tr>
<tr>
<td>AKTIA</td>
<td>-18,927</td>
</tr>
<tr>
<td>SHB</td>
<td>-314,740</td>
</tr>
<tr>
<td>ESSE</td>
<td>-305,092</td>
</tr>
<tr>
<td>MANDA</td>
<td>-56,065</td>
</tr>
<tr>
<td>APK</td>
<td>303,536</td>
</tr>
<tr>
<td>HEX</td>
<td>0,000</td>
</tr>
<tr>
<td>VK</td>
<td>373,651</td>
</tr>
<tr>
<td>AAB</td>
<td>8,565</td>
</tr>
<tr>
<td>DANSKE</td>
<td>0,227</td>
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<tr>
<td>UNIBAN</td>
<td>-297,646</td>
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<tr>
<td>B1</td>
<td>0,000</td>
</tr>
<tr>
<td>TARGET</td>
<td>1543,590</td>
</tr>
<tr>
<td>ACH</td>
<td>0,000</td>
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</tbody>
</table>

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**Bilateral Net Positions**

<table>
<thead>
<tr>
<th>Bank</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP</td>
<td>0,000</td>
</tr>
<tr>
<td>MERITA</td>
<td>10,638</td>
</tr>
<tr>
<td>LEONIA</td>
<td>233,953</td>
</tr>
<tr>
<td>OIKO</td>
<td>3,390</td>
</tr>
<tr>
<td>AKTIA</td>
<td>2,100</td>
</tr>
<tr>
<td>SHB</td>
<td>0,023</td>
</tr>
<tr>
<td>ESSE</td>
<td>0,021</td>
</tr>
<tr>
<td>MANDA</td>
<td>0,001</td>
</tr>
<tr>
<td>APK</td>
<td>0,000</td>
</tr>
<tr>
<td>HEX</td>
<td>0,000</td>
</tr>
<tr>
<td>VK</td>
<td>0,000</td>
</tr>
<tr>
<td>AAB</td>
<td>0,007</td>
</tr>
<tr>
<td>DANSKE</td>
<td>0,001</td>
</tr>
<tr>
<td>UNIBAN</td>
<td>0,001</td>
</tr>
<tr>
<td>B1</td>
<td>0,000</td>
</tr>
<tr>
<td>TARGET</td>
<td>0,000</td>
</tr>
<tr>
<td>ACH</td>
<td>0,000</td>
</tr>
</tbody>
</table>

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**Net Settlement**

<table>
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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>SP</td>
<td>0,000</td>
</tr>
<tr>
<td>MERITA</td>
<td>10,638</td>
</tr>
<tr>
<td>LEONIA</td>
<td>233,953</td>
</tr>
<tr>
<td>OIKO</td>
<td>3,390</td>
</tr>
<tr>
<td>AKTIA</td>
<td>2,100</td>
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<tr>
<td>SHB</td>
<td>0,023</td>
</tr>
<tr>
<td>ESSE</td>
<td>0,021</td>
</tr>
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<td>MANDA</td>
<td>0,001</td>
</tr>
<tr>
<td>APK</td>
<td>0,000</td>
</tr>
<tr>
<td>HEX</td>
<td>0,000</td>
</tr>
<tr>
<td>VK</td>
<td>0,000</td>
</tr>
<tr>
<td>AAB</td>
<td>0,007</td>
</tr>
<tr>
<td>DANSKE</td>
<td>0,001</td>
</tr>
<tr>
<td>UNIBAN</td>
<td>0,001</td>
</tr>
<tr>
<td>B1</td>
<td>0,000</td>
</tr>
<tr>
<td>TARGET</td>
<td>0,000</td>
</tr>
<tr>
<td>ACH</td>
<td>0,000</td>
</tr>
</tbody>
</table>

---

Running simulation... Data 1: Scale 0: Run 1 40%
### Appendix 2: Glossary of terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automated Clearing House (ACH)</td>
<td>An electronic clearing system in which payment orders are exchanged among financial institutions, primarily via magnetic media or telecommunication networks, and handled by a data-processing centre.</td>
</tr>
<tr>
<td>Batch</td>
<td>The transmission or processing of a group of payment orders and/or securities transfer instructions as a set at discrete intervals of time.</td>
</tr>
<tr>
<td>Bilateral net settlement system</td>
<td>A settlement system in which participants' bilateral net settlement positions are settled between every bilateral combination of participants.</td>
</tr>
<tr>
<td>Bilateral netting</td>
<td>An arrangement between two parties to net their bilateral obligations. The obligations covered by the arrangement may arise from financial contracts, transfers or both.</td>
</tr>
<tr>
<td>Caps</td>
<td>A risk management arrangement whereby limits are placed on the positions that participants in an interbank funds transfer system can incur during the business day; they may be set by each individual participant or by the body governing the transfer system; they can be set in multilateral net, bilateral net or (less commonly) gross terms and can be either a credit cap or a debit cap; for example, bilateral net credit caps, set by an individual participant, will constitute a limit on the credit exposure that that participant will accept vis-a-vis each other participant; in contrast, sender net debit caps, which may for example be set by the governing body of the clearing system based on a particular formula, limit the aggregate value of transfers that an individual participant may send to all other participants over and above its incoming transfers. Sender net debit limits may be either collateralized or uncollateralized.</td>
</tr>
<tr>
<td>Collateral</td>
<td>Assets pledged as a guarantee for the repayment of the short-term liquidity loans which credit institutions receive from central banks, as well as assets received by central banks from credit institutions as part of repo operations.</td>
</tr>
<tr>
<td>Counterparty</td>
<td>The opposite party in a financial transaction (e.g. in a transaction with the central bank).</td>
</tr>
<tr>
<td>Credit risk/exposure</td>
<td>The risk that a counterparty will not settle an obligation for full value, either when due or at any time thereafter. In exchange-for-value settlement systems, the risk is generally defined to include replacement cost risk and principal risk.</td>
</tr>
<tr>
<td>Credit transfer</td>
<td>A payment order or possibly a sequence of payment orders made for the purpose of placing funds at the disposal of the beneficiary. Both the payment instructions and the funds described therein move from the bank of the payer/originator to the receiver.</td>
</tr>
<tr>
<td>Cross-border payment</td>
<td>Payments transferred from one currency area to another.</td>
</tr>
</tbody>
</table>
Daylight Credit see Intraday credit
Daylight Exposure see Intraday credit
Daylight Overdraft see Intraday credit

Delivery versus payment (DVP) A mechanism in an exchange-for-value settlement system that ensures that the final transfer of one asset occurs if and only if the final transfer of (an)other asset(s) occurs. Assets could include monetary assets (such as foreign exchange), securities or

End-of-day gross settlement systems Funds transfer systems in which payment orders are received one by one by the settlement agent during the business day, but in which the final settlement takes place at the end of the day on a one-by-one or aggregate gross basis.

Final settlement Settlement which is irrevocable and unconditional.

Final transfer An irrevocable and unconditional transfer which effects a discharge of the obligation to make the transfer.

Finality An analytical rather than operational or legal term used to describe the point at which an unconditional obligation arises on the part of the initiating participant in a funds transfer system to make final payment to the receiving participant on the value

Funds Transfer System (FTS) A formal arrangement, based on private contract or statute law, with multiple membership, common rules and standardised arrangements, for the transmission and settlement of money obligations arising between the members.

Gridlock A situation that can arise in a funds or securities transfer system in which the failure of some transfer instructions to be executed (because the necessary funds or securities balances are unavailable) prevents a substantial number of other instructions from other participants from being executed.

Gross settlement system A transfer system in which the settlement of funds or securities transfers occurs individually on an order-by-order basis according to the rules and procedures of the system, i.e. without netting debits against credits.

Intraday credit Credit extended and reimbursed within a period of less than one business day. The ESCB will extend intraday credit (based on underlying assets) to eligible counterparties for payment systems purposes.

Irrevocable and unconditional transfer A transfer which cannot be revoked by the transferor and is unconditional.

Large-value funds transfer system (LVFT) A funds transfer system through which large-value and high-priority funds transfers are made between participants in the system for their own account or on behalf of their customers. Although, as a rule, no minimum value is set for the payments they carry, the average size of payments passed through such systems is usually relatively large.
Large-value funds transfer systems are sometimes known as wholesale funds transfer systems.

Large-value payments
Payments, which are mainly exchanged between banks or between participants in the financial markets and usually require urgent and timely settlement.

Liquidity risk
The risk that a counterparty (or participant in a settlement system) will not settle an obligation for full value when due. Liquidity risk does not imply that a counterparty or participant is insolvent since it may be able to settle the required debit obligations at some unspecified time thereafter.

Loro payments
Markka denominated cross border payments.

Multilateral net settlement system
A settlement system in which each settling participant settles (typically by means of a single payment or receipt) the multilateral net settlement position which results from the transfers made and received by it, for its own account and on behalf of its customers.

Multilateral netting
An arrangement among three or more parties to net their obligations. The obligations covered by the arrangement may arise from financial contracts, transfers or both. The multilateral netting of payment obligations normally takes place in the context of a multilateral net settlement system.

Net credit or net debit position
A participant's net credit or net debit position in a netting system is the sum of the value of all the transfers it has received up to a particular point in time less the value of all the transfers it has sent. If the difference is positive, the participant is in a net credit position; if the difference is negative, the participant is in a net debit position. The net credit or net debit position at settlement time is called the net settlement position. These net positions may be calculated on bilateral or multilateral basis.

Net settlement
The settlement of a number of obligations or transfers between or among counterparties on a net basis.

Net settlement system
A funds transfer system whose settlement operations are completed on a bilateral or multilateral net basis.

Netting
An agreed offsetting of positions or obligations by trading partners or participants. The netting reduces a large number of individual positions or obligations to a smaller number of obligations or positions. Netting may take several forms which have varying degrees of legal enforceability in the event of default of one of the parties.

Payment
The payer's transfer of a monetary claim on a party acceptable to the payee. Typically, claims take the form of banknotes or deposit balances held at a financial institution or at a central bank.

Payment instrument
Any instrument enabling the holder/user to transfer funds.

Payment lag
The time-lag between the initiation of a payment order and its final settlement.
<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Payment order/instruction</strong></td>
<td>An order or message requesting the transfer of funds (in the form of a monetary claim on a party) to the order of the payee. The order may relate either to a credit transfer or to a debit transfer.</td>
</tr>
<tr>
<td><strong>Payment system</strong></td>
<td>A payment system consists of a set of instruments, banking procedures and, typically, interbank funds transfer systems that facilitate the circulation of money.</td>
</tr>
<tr>
<td><strong>Payment versus payment (PVP)</strong></td>
<td>A mechanism in a foreign exchange settlement system which ensures that a final transfer of one currency occurs if and only if a final transfer of the other currency or currencies takes place.</td>
</tr>
<tr>
<td><strong>PMJ</strong></td>
<td>The Banks' Payment Clearing System in Finland. It is operated by the banks and covers both small and large value payments.</td>
</tr>
<tr>
<td><strong>POPS</strong></td>
<td>Data transmission and clearing system for express transfers and large-value cheques in Finland.</td>
</tr>
<tr>
<td><strong>Queuing</strong></td>
<td>A risk management arrangement whereby transfer orders are held pending by the originator/deliverer or by the system until sufficient cover is available on the originator/s deliverer's clearing account or under the limits set against the payer; in some cases, cover may include unused credit lines or available collateral.</td>
</tr>
<tr>
<td><strong>Real-time gross settlement system (RTGS)</strong></td>
<td>A gross settlement system in which processing and settlement take place in real time (continuously).</td>
</tr>
<tr>
<td><strong>Real-time transmission, processing or settlement</strong></td>
<td>The transmission, processing or settlement of a funds or securities transfer instruction on an individual basis immediately after the time it is initiated.</td>
</tr>
<tr>
<td><strong>Settlement</strong></td>
<td>An act that discharges obligations in respect of funds transfers between two or more parties.</td>
</tr>
<tr>
<td><strong>Settlement account</strong></td>
<td>An account held by a direct participant in the national RTGS system with the central bank for the purpose of processing payments.</td>
</tr>
<tr>
<td><strong>Settlement lag</strong></td>
<td>In an exchange-for-value process, the time-lag between entering into a trade/bargain and its discharge by the final exchange of a financial asset for payment.</td>
</tr>
<tr>
<td><strong>Settlement risk</strong></td>
<td>A general term used to designate the risk that settlement in a transfer system will not take place as expected. This risk may comprise both credit and liquidity risk.</td>
</tr>
<tr>
<td><strong>Settlement system</strong></td>
<td>A system used to facilitate the settlement of transfers of funds or financial instruments.</td>
</tr>
<tr>
<td><strong>Solvency risk</strong></td>
<td>The risk of loss due to the failure (bankruptcy) of an issuer of a financial asset or due to the insolvency of the counterparty.</td>
</tr>
<tr>
<td><strong>Systemic risk</strong></td>
<td>The risk that the failure of one participant in a transfer system, or in financial markets generally, to meet its required obligations will cause other participants or financial institutions to be unable to meet their</td>
</tr>
</tbody>
</table>
obligations.

Trans-European Automated Real-time Gross settlement Express Transfer system (TARGET) The TARGET system is defined as a payment system composed of one RTGS system in each of the countries which participate in Stage Three of EMU and the European Central Bank (ECB) payment mechanism. RTGS systems of non-participating countries may also be connected, provided that they are able to process the euro alongside their national currency. The domestic RTGS systems and the ECB payment mechanism are interconnected according to common procedures ("Interlinking") to allow cross-border transfers throughout the European Union to move from one system to another system.

Transfer Operationally, the sending (or movement) of funds or securities or of a right relating to funds or securities from one party to another party by: (1) the conveyance of physical instruments/money; (2) accounting entries on the books of a financial intermediary; or (3) accounting entries processed through a funds and/or securities transfer system. The act of transfer affects the legal rights of the transferor, transferee and possibly third parties in relation to the money balance, security or other financial instrument being transferred.

Transfer system A generic term covering funds transfer systems and exchange-for-value systems.

Source: European Monetary Institute; Payment Systems in the European Union, Frankfurt am Main, April 1996