Risto Koponen – Kimmo Soramäki

Intraday Liquidity Needs in a Modern Interbank Payment System

A Simulation Approach

SUOMEN PANKKI
Bank of Finland

BANK OF FINLAND STUDIES E:14 • 1998

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Abstract

In this study three topics in particular are analysed. First, the adequacy of intraday credit limits in the existing and planned Finnish interbank funds transfers systems are studied. Secondly, the efficiency of two actual and two hypothetical payment settlement systems is analysed and, thirdly, the effects of optimization features such as queuing, payment splitting and netting of queued transfers are examined.

The data used in the study consist of four days of actual payment data provided by the major banks operating in Finland and 100 days of generated data, where the order and number of daily payments is varied. The study is based on results generated by a payment systems simulator that was developed at the Bank of Finland. The simulator is capable of simulating a wide variety of hypothetical settlement and banking structures as well as various optimization features.

The results show that the existing intraday credit limits of the Finnish banks will be sufficient in the settlement system to be used in Stage Three of Economic and Monetary Union. However, some queuing of payments is expected to take place if liquidity is not increased. Systems employing more real-time gross settlement were found to be more efficient in terms of speed of settlement and usage of liquidity per value of payments settled. An RTGS system 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 delay substantially. The main effect of the netting of queued transfers was that it solved gridlock situations during the day and thereby reduced settlement delay.

Keywords: payment systems, clearing/settlement, liquidity,
simulation, optimization methods

Tiivistelmä

Tutkimuksessa on kolme maksujen katteensiirtojärjestelmiin liittyvää pääaihetta. Sekä Suomen Pankin nykyistä että vuoden 1999 alussa toimintansa aloittavaa sekkitilijärjestelmää tarkastellaan päivänsisäisen luoton limiittien riittävyyden kannalta. Likviditeettitarpeen määrän ja likviditeetin riittämättömyydestä aiheutuvan katteensiirtoviipeen suhdetta kvantifioidaan brutto- ja nettokatteensiirron erilaisilla suhteellisilla osuuksilla. Lisäksi arvioidaan erilaisten optimointimenetelmien, kuten maksujen jonotuksen, suurten maksujen pilkkomisen ja jonottavien maksujen nettoutuksen, vaikutuksia likviditeetin käyttöön ja jonotukseen.

Tutkimuksessa käytetään merkittävimpien Suomessa toimivien pankkien toimittamaa neljän päivän maksuaineistoa ja tämän perusteella muodostettua sadan päivän aineistoa, jossa maksujen lukumäärää ja päivänsisäistä järjestystä on varioitu. Tutkimus perustuu Suomen Pankissa kehitetyn maksujärjestelmäsimulaattorin avulla saatuihin tuloksiin. Simulaattorin avulla on mahdollista simuloida lukuisia erilaisia katteensiirtojärjestelmiä ja tutkia eri optimointimenetelmien vaikutuksia katteensiirtoon.

Tulosten perusteella pankkien nykyiset päivänsisäisen luoton limiitit riittävät myös talous- ja rahaliiton kolmannen vaiheen alussa. Vähäistä maksujen jonotusta on kuitenkin odotettavissa, mikäli likviditeettiä ei lisätä. Reaaliaikaisten bruttoselvitysjärjestelmien havaittiin toimivan huomattavasti tehokkaammin likviditeetin käytön ja katteensiirtoviipeen kannalta kuin nettoperiaatteella toimivien järjestelmien. Puhtaassa RTGS-järjestelmässä, joka toimii samalla likviditeetillä kuin järjestelmä, jossa maksut selvitetään nettoperiaatteella päivän lopussa, maksujen lopullinen selvitys on huomattavasti nopeampaa. Kaikkien optimointimenetelmien havaittiin tehostavan likviditeetin käyttöä ja vähentävän katteensiirron viivettä.

Asiasanat: maksujärjestelmät, clearing/settlement, likviditeetti, simulointi, optimointimenetelmät

Foreword

In spring 1997 a project was started in the Bank of Finland's Financial Markets Department in conjunction with the Finnish banks to determine how changes planned for the Finnish interbank payment system would affect the liquidity needs of banks participating in the settlement system. For this purpose a simulation model was developed. Payment data for the simulations were gathered in May 1997 and the initial results were presented to the participating banks in autumn 1997. Subsequently, the simulator was further improved and can now handle a wide variety of hypothetical payment systems. This study builds on the results and insights gained from the whole project and the improved simulator.

In the course of writing, many people have contributed to this study. Our special thanks go to Kirsti Tanila, the third member of the project team. She laboured untiringly in preparing the payment data for the simulations and helped us here and there throughout the study, particularly regarding questions of mathematics and statistics. Harry Leinonen was involved in the project early on and provided invaluable ideas and suggestions over the course of the project. We also thank Heikki Koskenkylä, Veikko Saarinen, Juha Tarkka and Jouko Vilmunen for valuable suggestions and comments made during the project. We would also express our thanks to Karlo Kauko, Mikko Niskanen and Jukka Vesala for useful comments that improved the final version of the text. We also thank Glenn Harma for improving the English and making the text much more readable as well as for making the terminology more consistent. Seija Leino and Anneli Heikkilä we would like to thank for overseeing the printing process.

Last but not least, we want to thank all the bank personnel who participated in the project for their helpful cooperation and efforts in gathering the payment data from their internal sources. Without their contribution, the study would simply have not been possible.

Helsinki, December 1998
Risto Koponen and Kimmo Soramäki

Contents

1 Introduction

Over the past few decades, financial activity has increased significantly. This is mainly due to technological advance, 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 to a greater reliance on gross settlement, in which payments are settled individually. 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 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. There are several factors that affect banks' liquidity needs such as the relative importance of net and gross settlements and the specific liquidity optimization methods used.

To study the effects of different concentrations of net and gross settlement and different optimization methods on a payment system's liquidity needs, liquidity usage and settlement delay, the Bank of Finland developed a payment system simulator. 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.

This study uses the above mentioned simulation approach and it has three main objectives:

1. to examine the adequacy of current intraday credit limits of banks operating in Finland under certain pre-selected payment systems
2. to examine the efficiency of the pre-selected payment systems from the standpoint of liquidity needs and settlement delay
3. to examine the effects of various liquidity optimization methods on liquidity needs and settlement delay

Both actual Finnish payment data as well as generated data based on the actual data were used in the simulations.

Four pre-selected payment systems were simulated, two actual and two hypothetical. The system used in Finland at the time the payment data were gathered is labelled here the RTGS-with-subnetting structure. The system that will be launched at the start of the third stage of EMU is referred to as the Hybrid structure. The latter payment system was simulated with and without estimated transactions going through the TARGET network. The hypothetical Advanced Hybrid structure entails even more extensive use of gross settlement than the Hybrid structure. The effects of optimization methods were studied in an RTGS-with-queuing structure.

This study is divided into eight chapters. The next chapter, 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 we present the assumed dynamics of optimization methods in RTGS systems.

Chapter 4 is devoted to the payment systems simulator. A brief overview of the main properties of the simulator is presented. More information on the simulator can be found in appendix 2. Chapter 5 focuses on the simulations and the payment data used. The basic characteristics of the simulated payment systems are explained, and the data collection process and the procedures for creating additional data are presented. Additional information on Finnish interbank payment systems can be found in appendix 3. More information on the generation of additional days and a discussion of the reliability of the data is contained in appendix 4.

Chapter 6 presents the methods of calculating liquidity boundaries used in the simulations and explains the indicators of liquidity usage and settlement delay. Chapter 7 is devoted to a presentation of the findings of this study. The results are organized into four main parts. In the first part, the upper and lower bounds of liquidity needs are given for the pre-selected scenarios. In the second part the relationship between payment turnover and liquidity need is studied. In the third part the adequacy of liquidity in the pre-selected settlement scenarios and their relative efficiencies are analysed and in the fourth part the effects of the selected optimization methods are compared. Finally, the most important results are summed up in chapter 8 and some interesting, but still unresolved, questions that have arisen during this project are presented.

2 Liquidity and risks in 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 the 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.

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. Arrangement of intraday repos is analytically equivalent to required collateralization of overdrafts.

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 well command substantial liquidity premia and hence generate lower returns. The costs become obvious if the banks are forced to hold substantial amounts of such securities merely for settlement purposes. It has been argued 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.[1]

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. 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 scarce and creates an incentive 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 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. 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. At least some of the payments are likely to be time-critical, which means that any delay in settlement will generate costs to the sending or receiving bank. These costs may be implicit, in the form of a deterioration in customer service, or explicit, in the form of agreed sanctions.

The primary aim of this study is to examine, by means of simulations the efficiency of different types of payment systems and the effects of different optimization methods on liquidity needs and settlement delays.

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[1] Folkerts–Landau, Garber and Schoenmaker 1996, p. 35.

2.2 Risks in the provision of liquidity

Regarding payment system participants' intraday liquidity needs, the major risks inherent in the system are credit and counterparty risks, liquidity and gridlock risks, and systemic risk. These risks are discussed in more detail in subsequent sections.

There are other risks associated with payment systems such as operational, environment, and clearing and settlement risks. Although these risks are also important and may constitute significant problems to the payment system and its participants, they are not of the same level of importance in the context of this study and hence will not be further discussed.

2.2.1 Counterparty risk

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.[2] 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[3] (DVP) in securities transactions and payment vs payment[4] (PVP) in foreign exchange transactions may induce greater customer demand for intraday funding. This is because DVP and PVP require timely funding, which can complicate customers' liquidity management.

Because daily debt positions between banks can be very large, several measures have been taken to reduce risks in systems that

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[2] Leinonen 1998, p. 14.

[3] 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.

[4] PVP is another mechanism that ensures quid pro quo in a transaction. In this case one currency is exchanged for another.

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 banks credit receiving customers’ accounts before covering funds are transferred, they face 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 payments (see section 2.2.3).

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.

2.2.2 Liquidity and gridlock risks

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. Types of liquidity risk include 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. Poor liquidity management may lead to repeated payment delays, compensation claims and, if prolonged, to a loss of customers to rivals.[5]

A type of liquidity risk that is associated particularly with queuing arrangements is gridlock risk. Gridlock has been variously defined, eg as a situation in which the failure of one bank to execute transfers prevents a substantial number of other participants' transfers from being executed.[6]

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 1. **Payment system liquidity states**
(NL_i = net liquidity for participant i)

	Queued payments get settled	Queued payments do not get settled
$NL_i < 0$	(not applicable)	illiquid
$NL_i \geq 0$	liquid	gridlocked

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[5] Leinonen and Saarinen, p. 36.

[6] BIS 1997, p. 17.

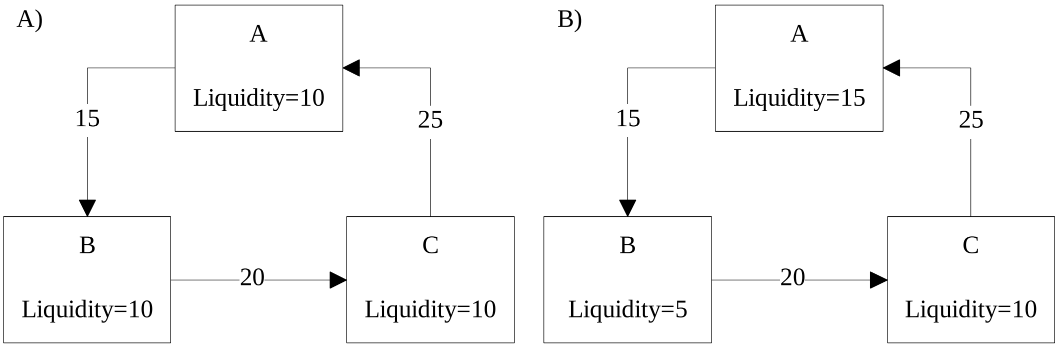
A system is liquid if the net liquidity position of each participant is positive or zero. A bank's net liquidity position at any moment is the net amount of its queued incoming and outgoing transfers plus the sum of actual funds that it has available for settling payments and any credit extensions. The system is illiquid if any participant is illiquid. How critical such illiquidity is depends on how time-critical and important the pending transfers are. 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 other optimization method is applied.

Figure 1b depicts a situation where bank A has liquidity worth 15 and bank has 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.

Figure 1. **Gridlock in an RTGS system**



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. 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.

2.2.3 Systemic risk

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. If it spreads, such a disturbance may expand into an overall systemic crisis, which can jeopardize the operation of the whole financial system as well as the real economy.

Systemic risk may be caused by the failure of a critical part of a payment system, viz its information 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.

Systemic risk is also associated with the possibility that in the event of realization or contagion of one or more of the basic risks discussed in previous sections on a sufficiently large scale can jeopardize the operation the whole system.[7]

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[7] Leinonen and Saarinen 1998, p. 39.

2.3 Boundaries for liquidity needs

2.3.1 Theoretical bounds

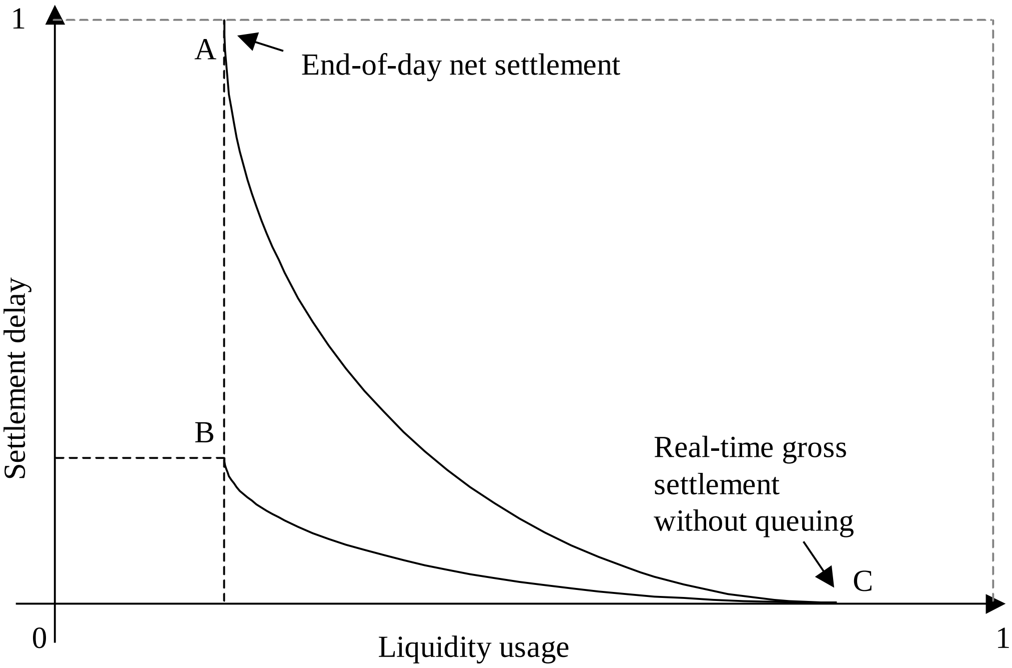
The relationship between liquidity need and settlement delay in different payment settlement systems is analysed in this study within the framework depicted in figure 2. The liquidity used by the settlement system (x axis) consists of risk-free resources such as reserves held at, or intraday credit received 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.

In the following, we present the framework used to analyse different implementations of real-time gross settlement (RTGS) and time designated net settlement (TDNS) systems. 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, ie 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. The need for the third and fourth assumptions and the effects of relaxing them are explained in section 2.3.2.

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



BC: amount of reserves and intraday credit in RTGS system with queuing

AC: number of daily net settlements in TDNS system without counterparty risk

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[8]). This is illustrated in equation 1 and represented by point B in figure 2.

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[8] 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.

$$(1) \quad LB_{t(heoretical)} = \min\left[0 \ , \left(\sum_{t=0}^{T} P_t^I - \sum_{t=0}^{T} P_t^O\right)\right]$$

Equation 1: Theoretical lower bound for a bank's daily liquidity need in an RTGS system with queuing (P^I = value of incoming payment, P^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.

$$(2) \quad UB_{t(heoretical)} = \min\left[0 \ , \min_{t} \sum_{i=0}^{t} (P_i^I - P_i^O) \ \ \forall \ \ t \in [0,T]\right]$$

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^I = value of incoming payments at time i, T = end of day)

The curve segment BC shows the tradeoff 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.[9] A bank's liquidity need equals the upper bound for its liquidity in an RTGS system with queuing, ie 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 needs. The curve segment AC shows this tradeoff. If the number of settlements is increased to the point where net settlement is executed after each transaction, the system becomes in effect a real-time gross settlement system without queuing. This is shown as point C in figure 2.

So far we have discussed only systems without counterparty risk. 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.

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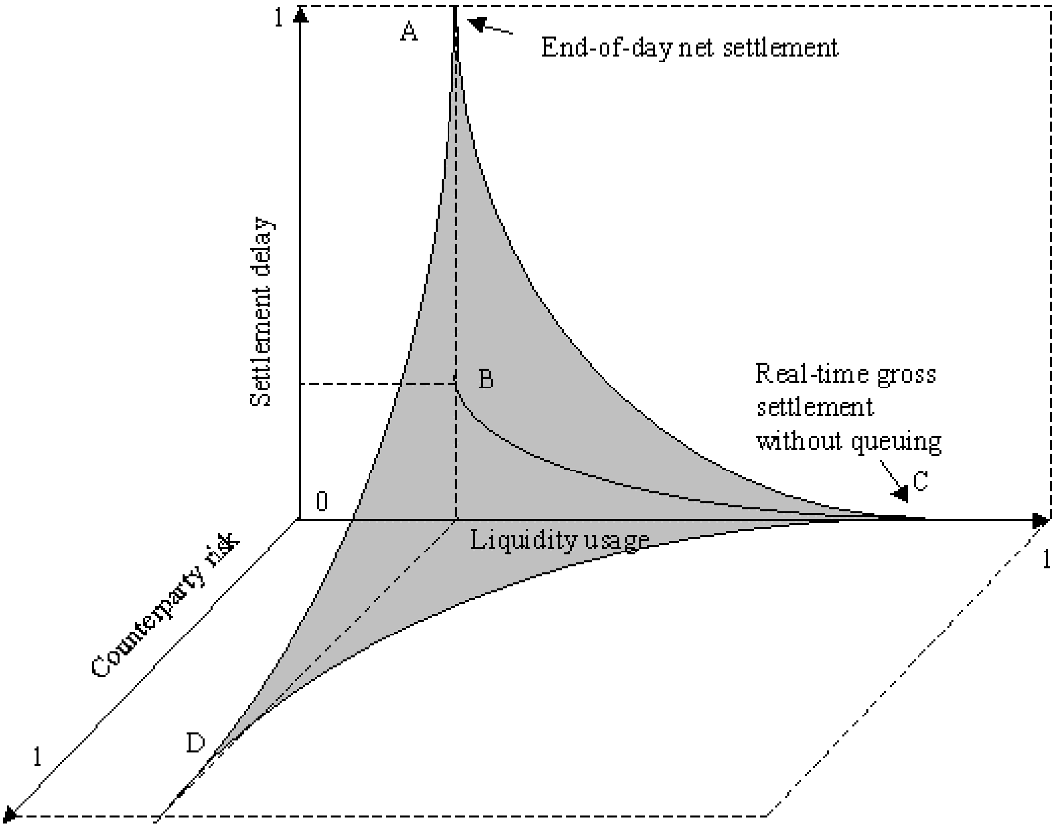
[9] It is assumed that there is no internal queuing within the banks, as explained in the assumptions for this framework.

Figure 3. **Relationship between a bank's liquidity usage, settlement delay and counterparty risk in an RTGS or TDNS system with counterparty risk**



BC: amount of reserves and available intraday credit in RTGS system

AD: exposure to counterparty risk in TDNS system with counterparty risk

AC: number of daily net settlements in TDNS system without counterparty risk

DC: number of daily net settlements in TDNS system with counterparty risk

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.

The curve AD representing the tradeoff between settlement delay and risk is concave. 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.

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.

2.3.2 Real bounds

If time-critical transfers and payment prioritization are added to the system (ie assumptions 3 and 4 in section 2.3.1 are relaxed), the upper and lower liquidity bounds will change. In this study a bank's bounds within a system with these features are referred to as its real upper and lower bounds (UB_r and LB_r). In actual payment systems at least some payments are likely to be time-critical.

Simulations were necessary for quantifying real bounds. In calculating the real lower bound, an account holder was assumed to hold the smallest possible amount of liquidity for successful settlement of its payments. This amount is equal to its theoretical lower bound of liquidity (LB_t), ie the net amount of all its incoming and outgoing payments throughout the day. The daily limits were raised as needed for timely settlement of time-critical transfers. The resulting maximum liquidity usage for each account holder during the day became its real lower bound for liquidity need.

The theoretical upper bound (UB_t) is calculated as the minimum cumulative net amount of incoming and outgoing payments throughout the day. For the real upper bound (UB_r), the prioritization and time-criticalness of payments were introduced in the simulations. In principle, these upper bounds should not be affected, as no queuing takes place at this liquidity level. However, there are technical features in the following simulated payment system structures that cause these bounds to change (see section 7.1.1)

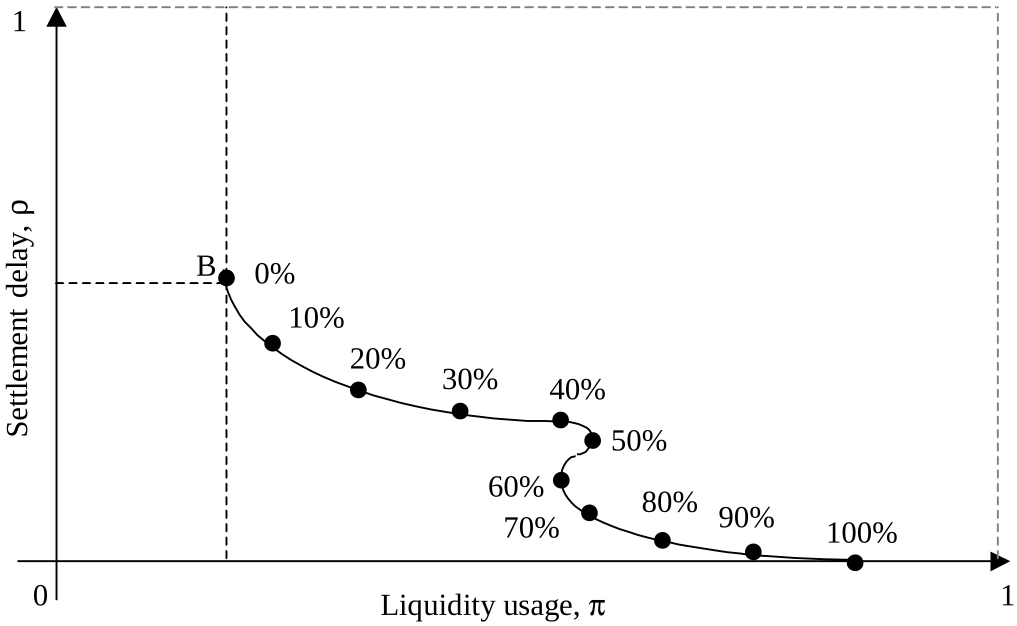
In a system without time-critical payments, the theoretical lower bound (LB_t) is always lower than or equal to the theoretical upper bound (UB_t). However, this may not be the case if time-criticalness of payments is introduced, ie some payments must be settled immediately upon entry into the system or within a specified period of time, as eg those in settlement of net positions of a net settlement system.

Simulations on the liquidity bounds showed that the real lower bound (LB_r) can be higher than the real upper bound (UB_r). This may be due the inclusion of time-criticalness and prioritization of payments and the effects of queuing on a bank's liquidity. If a bank has payments queued, the receivers of these payments do not get the funds and so may have to raise their intraday credit limits in order to obtain liquidity needed for settling any time-critical payments. If a bank has to raise its credit limit by more than it can substitute liquidity for settlement delay during the day, its real lower bound will be higher than its real upper bound. At the latter liquidity level, no queuing is needed and the bank gets its payments settled immediately without needing to raise its credit limit during the day, as the liquidity circulates efficiently in the system.

If the real lower bound (LB_r) is higher than the real upper bound (UB_r) for an account holder, it faces a concave relation between liquidity usage and settlement delay. The actual need for liquidity increases as the liquidity available to the banking system decreases. Concavity is also possible in other cases. A concave segment can be located any place on the curve between the upper and lower bounds. This is illustrated in figure 4 and occurs if

1 a reduction of liquidity for the banking sector (in the figure from a liquidity level of 60 per cent to 50 per cent)
2 causes increased queuing of payments and, as a result,
3 one or more of the banks do not receive sufficient liquidity in the form of incoming payments to cover time-critical payments, thus
4 forcing the banks to raise their intraday credit limits to be able to settle these payments and
5 the increase in the limits is greater than the reduction in liquidity referred to in point 1.

Figure 4. **Possible relationship between liquidity usage and settlement delay in a system with time-critical transfers and liquidity levels of 0- 100%**



Analytically, this means that if the banks select adequate liquidity levels, they can settle their payments smoothly and with smaller liquidity needs. A bank may however select a liquidity level that produces a suboptimal result for all participants in the system.

In the hypothetical situation depicted in figure 4, a system operating at a 60 per cent level of liquidity will have the same liquidity need as if it were operating at a 40 per cent liquidity level but will have less settlement delay. However, if the banks select a 50 per cent liquidity level, they will have longer settlement delays and greater liquidity usage than with a 60 per cent level of liquidity. Thus liquidity levels between 40 per cent and 60 per cent are inferior choices for the banking sector.

A liquidity level of 0 per cent is equivalent to the lower bound for liquidity need and a level of 100 per cent to the upper bound. The concept of liquidity levels as used in this study is explained in section 6.1.

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. An RTGS system provides continuous intraday finality for the processed transfers.[10]

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 pricing. These factors are usually externally determined by authorities and will not be addressed further within this context.

This study concentrates on system-based optimization methods and so the simulation of banks' behaviour is beyond its scope. 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.

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[10] BIS 1997, p. 10.

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.

Thus queues can be divided on the basis of management into centralized and decentralized queues. They can also be divided on the basis of location into system and internal queues. 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.[11] Centrally managed queues may also include features that allow the banks to manage their own liquidity.

Different queuing systems may 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 Reordering of queued payments

Reordering of queued payments is one way of solving a gridlock and of enhancing the system’s liquidity circulation. The reordering can be effected by a central participant according to predefined rules or by the banks themselves. By relaxing the FIFO rule and reordering the

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[11] BIS 1997, p. 24.

settlements, it may be possible for the banks to settle all their queued payments.

A variation of the FIFO rule is the ‘Bypass FIFO’ rule. In this case, an earlier entry into the queue has priority over subsequent entries except that, if the paying bank does not have covering funds, an attempt is made to settle the next payment.

Instead of applying the FIFO rule, an algorithm can be used that maximizes either the number or value of payments that get settled with the available liquidity.[12] This problem can be compared to the ‘knapsack’ problem in operations research, ie the situation where items, each having a cost and a value, are included in a collection so that the total value is maximized subject to the total cost being less than a specified amount. If such an algorithm is used for queuing, liquidity usage is optimized as payments are selected from a queue so as to maximize the total value of payments settled, subject to the requirement that the total value is less than the amount of liquidity available to the paying bank. One disadvantage of this type of queuing arrangement is that some payments may remain unsettled in the queue for a long time while the FIFO rule is not in effect.

The reordering of payments can also be useful in solving a situation where one large payment prevents several other equal-priority payments from being settled. However, it should be noted that the reordering of payment queues may entail legal risks.

3.1.3 Net settlement of queued payments

One way to solve a gridlock 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 our definition, 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 2.2.2.

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[12] Boeschoten W C 1989, p. 8.

(3) $\sum_{j=1}^{N} P_j^{I,i} - \sum_{k=1}^{M} P_k^{O,i} < L_i$ 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. Because system participants may prefer different subsets, a legally tenable procedure must be agreed in order to solve such situations.[13] 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 can reduce (in some cases substantially) 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.

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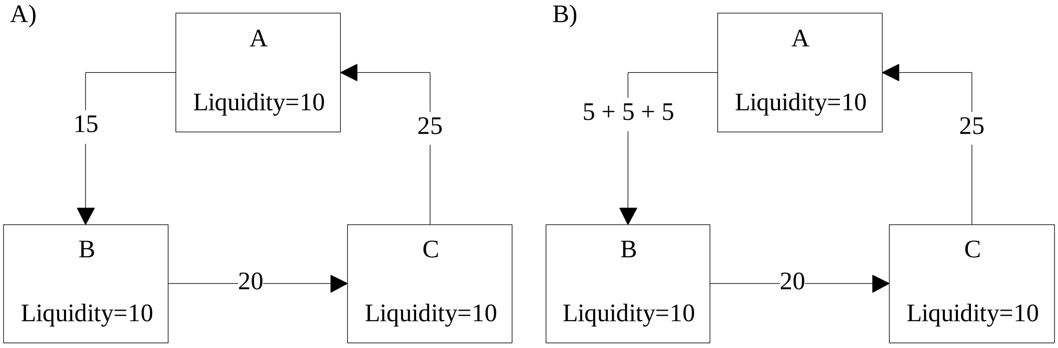
[13] BIS 1997, p. 30.

3.1.4 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. 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 5. **Solving a gridlock by splitting payments**



The effect of payments splitting is depicted in figure 5. 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 payments are split centrally, the splitting can be effected in a way that is transparent to the participants.[14]

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[14] Leinonen 1998, p. 18.

The effectiveness of splitting of 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.

3.2 Action-based optimization methods

The first of the action-based methods, ie rules or codes of conduct for settlement behaviour of participants, can also 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 (eg TARGET, EBA-clearing, correspondent banking, ECHO, EAF) and, at least in Finland, the more extensive use of RTGS and the projected increases in numbers 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 Payment systems simulator

4.1 Overview of the simulator

The simulation runs for this study were done using the payment systems simulator developed by 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. But 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 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 discrete 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 itself does not impose a limit on the maximum number of account holders in the system.

Properties of account holders include account limits and starting balances. A bank’s starting balance can be defined 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 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) and the settlement agent 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 (eg 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.

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

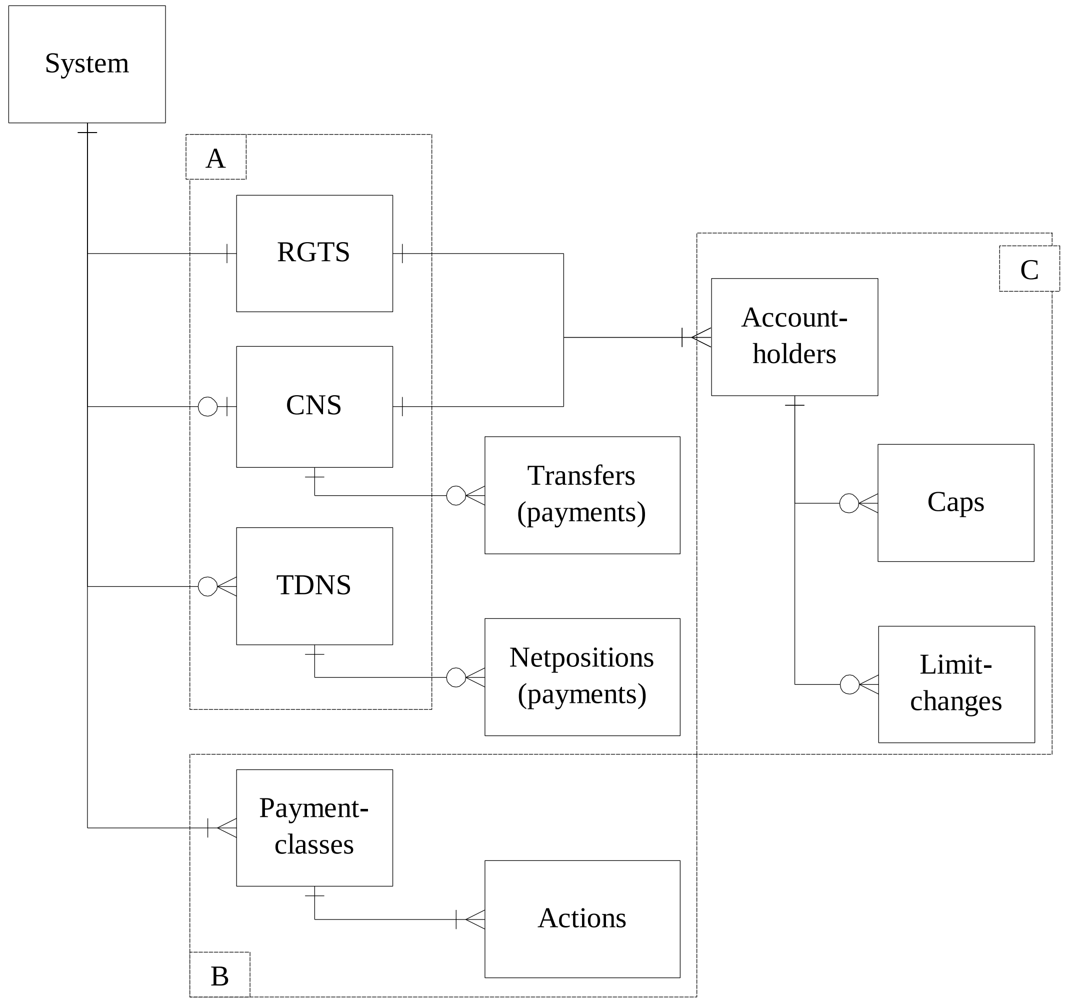
In this section a more technical description of the simulator is presented. First we present the general construction of the simulator, and in sections 4.2.1 to 4.2.3 the logic of the most important parts of the simulator is explained. The flow charts given are simplified presentations of the actual 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 6, 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.

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.

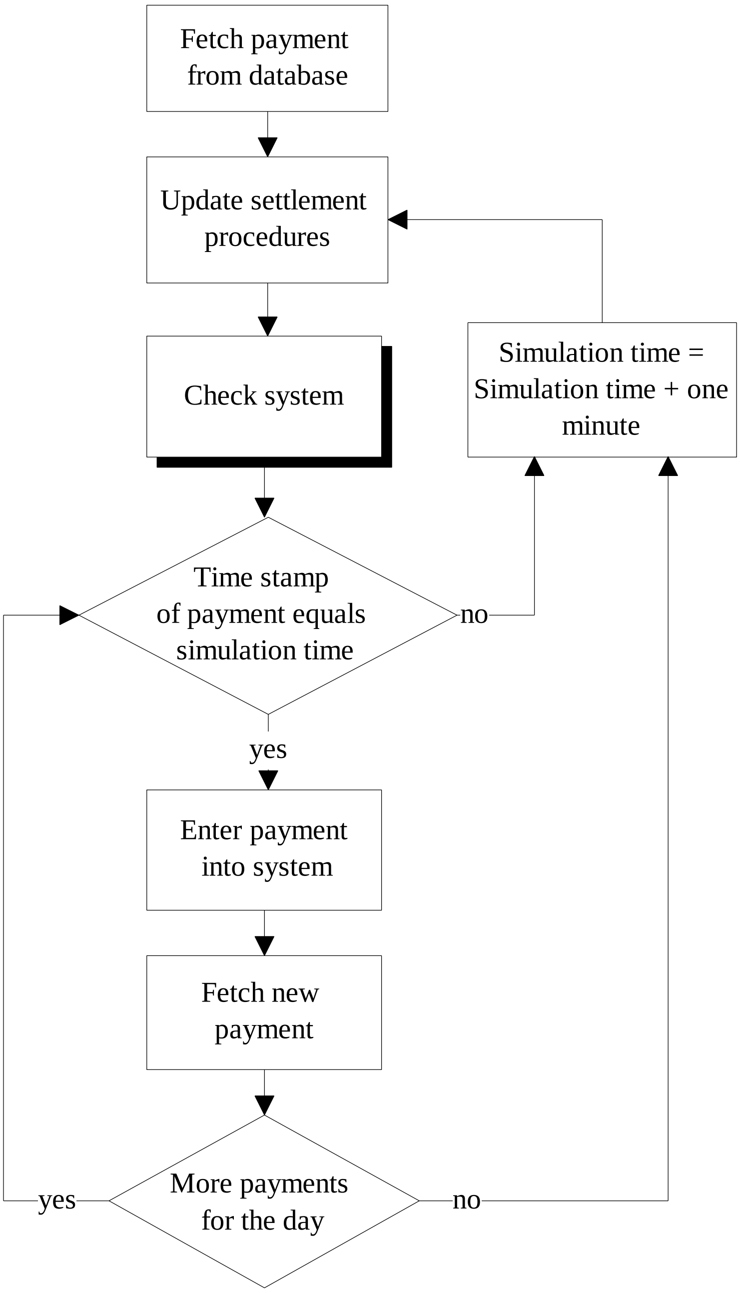
Figure 6. **Payment systems simulator object model**



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.

Figure 7. **Overview of the simulation run**[1]



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[1] A shadowed box in the figures means that the procedure is explained in more detail later in this section.

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[15] 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 7.

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.

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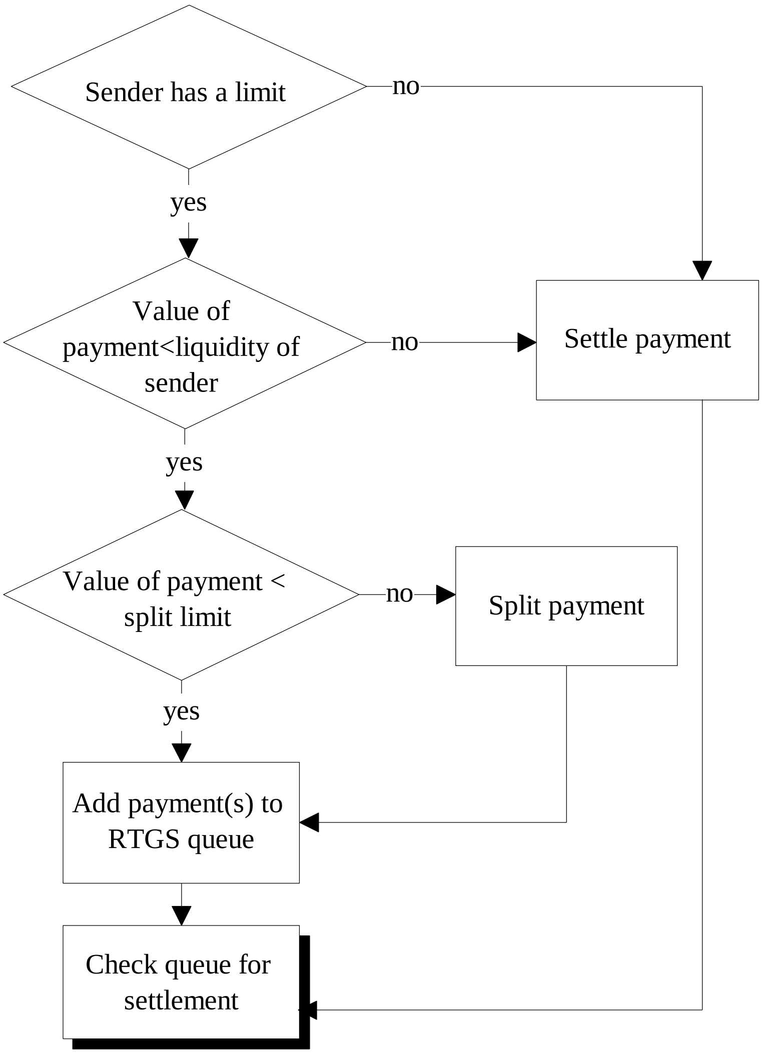
[15] These actions are: real-time gross settlement, secured net settlement, time designated net settlement, RTGS queued, CNS queued, postponed to next day, and not settled.

4.2.3 RTGS system

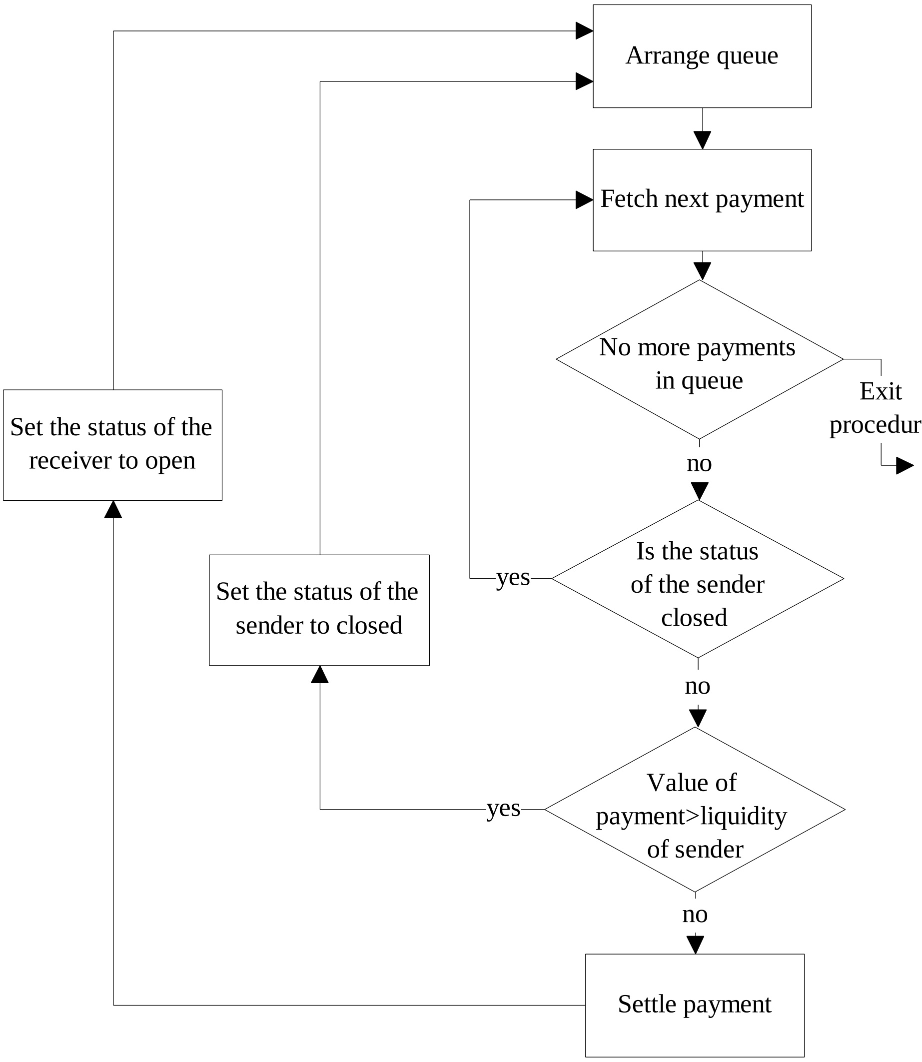
If a payment is forwarded to the RTGS system, the sender's credit limit is checked. If the account holder does not have unlimited credit and its liquidity is not sufficient to cover the payment, the payment is queued; otherwise it is settled. Account holders with unlimited credit might be the central 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 8, and procedures for settling the queued transfers are depicted in figure 9.

Figure 8. **Overview of the RTGS system in the simulator**



At the start of the procedure in figure 9, 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, ie 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.

Figure 9. **Overview of an RTGS queue in the simulator**



5 Simulations and payment data

5.1 The simulated payment systems

The pre-selected payment system structures and policies are studied in order to evaluate the adequacy of existing credit limits in the Finnish interbank payment system. Also the efficiency in terms of banks intraday liquidity usage and queuing is studied within these structures. The effects of the different optimization methods are studied within an environment where all payments are settled by RTGS. The payment system structures simulated are explained in the following sections.

5.1.1 Pre-selected payment system structures

The simulated payment system structures and policies are RTGS with subnetting, Hybrid, Advanced Hybrid and RTGS with queuing. The RTGS-with-subnetting structure refers to the settlement policy and structure used in May 1997. The Hybrid structure reflects the situation as of the start of 1999, and the Advanced Hybrid structure is a hypothetical structure with even more extensive use of gross settlement.

The characteristics of the settlement scenarios used in the simulations are shown in table 2 and the shares of the value of payments settled via the three types of settlement systems are summed up in table 3. The PMJ payments include retail payments between banks such as debit transfers, ATM withdrawals, debit card payments and recurrent payments. POPS payments are mainly large-value customer payments that comprise express transfers or cheques. Loro payments are markka-denominated foreign payments. All other payments were settled in real-time on a gross basis in all scenarios. For a more detailed description of the Finnish interbank payment system, see appendix 3.

Table 2. **Settlement scenarios**

	RTGS with subnetting	Hybrid	Advanced Hybrid	RTGS with queuing
PMJ payments	Net settlement at 15:45	Net settlement at 01:00 and 15:45	Net settlement at 01:00 and 15:45	RTGS (bilateral positions)
POPS payments	Within PMJ net settlement	Over limit: RTGS Under limit: CNS	RTGS	RTGS
Loro payments	Net settlement at 14:30	≥ FIM 50 000: (ECU 8300) RTGS < FIM 50 000: within PMJ net settlements	≥ FIM 50 000: (ECU 8300) RTGS < FIM 50 000: within PMJ net settlements	RTGS
Financial markets transactions	Net settlement at 13:00	RTGS	RTGS	RTGS

Table 3. **Shares of value settled using different settlement systems in the pre-selected settlement structures, %**

	Settled by		
	RTGS	TDNS	CNS
RTGS with subnetting	34.6	65.4	0.0
Hybrid	88.4	6.3	5.3
Advanced Hybrid	93.7	6.3	0.0
RTGS with queuing	100.0	0.0	0.0

The results concerning the differences between the net-based RTGS and Hybrid structures are of great importance because both are applied in existing payment systems. The former reflects the situation where payment data are gathered and the latter is the EMU-compatible payment settlement environment as at the start of Stage Three of EMU.

These simulations enable determination of whether the current liquidity reserves possessed by the payment system participants are sufficient also for the EMU-compatible payment system environment. If liquidity shortfalls exist, an injection of liquidity, eg in the form of an increase in the system account balances or intraday overdraft limits might be required to ensure smooth operation of the payment system.

The simulation runs for different structures are presented in table 4. As each of the pre-selected structures was simulated with both actual and generated payment data with existing and theoretical limits, the total number of simulations for each structure was 1248.

Table 4. **Pre-selected payment system structures**

	RTGS with subnetting	Hybrid	Advanced Hybrid	RTGS with queuing
Account holder scenario	The Finnish banking system[1]			
Systems scenario	- no optimizations	- queuing of payments - netting of queues every 20 minutes - prioritization of payments	- queuing of payments - netting of queues every 20 minutes - splitting of payments worth over ECU 16.6 mill. - prioritization of payments	- queuing of payments - prioritization of payments
Settlement scenario	RTGS with subnetting	Hybrid	Advanced Hybrid	RTGS with queuing
Intraday credit limits	Existing limits and 10%- point intervals between theoretical lower and upper bound of liquidity			
Simulation period	4 days of actual payment data and 100 days of generated data			

[1] Only banks participating in the simulation project were included; these accounted for over 90 per cent of payments in terms of value and number.

5.1.2 Simulations on the effect of TARGET transactions

The TARGET system will be operational at the start of Stage Three of EMU, and this may have significant effects on the liquidity needs of payment system participants. The TARGET environment was simulated using the Hybrid structure with payment data including estimated transactions flowing through the TARGET network. Simulation enables one to evaluate the impact of TARGET payments on payment system participants' liquidity needs and queuing, as compared to the Hybrid structure without the TARGET transactions.

Table 5. **TARGET-scenarios**

Account holder scenario	The Finnish banking system + 1 account holder TARGET bank[1]
Systems scenario	Netting of queues every 20 min.
Settlement scenario	Hybrid
Intraday credit limits	Upper and lower bounds of liquidity
Simulation period	25 times 4 days of actual payment data with estimated target transactions varied (short- and medium-term scenarios)

[1] The Target bank is a hypothetical account holder that represents all banks in the TARGET network outside of Finland. It has unlimited intraday credit and is excluded from the calculation of the results.

To estimate the effects of TARGET transactions, only upper and lower liquidity bounds were studied. Since 100 days were simulated for both the short-term and medium-term scenarios, the total number of simulated days is 400.

5.1.3 Effects of optimization methods

Optimization methods are studied within the RTGS-with-queuing structure with 100 days of generated 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 three time intervals and the splitting of payments with four different split limits. These are summarized in table 6.

Our purpose in running these simulations was to evaluate whether the level of liquidity can be reduced via technical changes without affecting the smooth operation of the system and rapid settlement of payments.

As each of the optimization methods was simulated with generated payment data and eleven theoretical intraday credit limits, the total number of simulation runs was 8800.

Table 6. **Simulations on optimization methods**

Account holder scenario	The Finnish banking system			
Systems scenario	No splitting	Top 10% of payments split	Top 5% of payments split	Top 1% of payments split
	Top 1‰ of payments split	Netting of queues every 20 minutes	Netting of queues every 5 minutes	Netting of queues every minute
Settlement scenario	RTGS with queuing and without payment prioritization			
Intraday credit limits	10%- point intervals between theoretical lower and upper bound of liquidity			
Simulation period	100 days of generated data			

5.2 The data used in the simulations

In the simulations both actual and generated data are used. In this section we present some characteristics of the actual and generated data as well as the rationale for use of the latter. Since, at the time of writing, the TARGET system was not operational, the estimation of TARGET transactions is also explained.

5.2.1 Collected data

The payment data used in the simulations were provided by eight of the major banks operating in Finland.[16] Records of the outgoing payments of each of the participating banks were collected for the purpose of studying the effects of changes in the Bank of Finland's funds transfer (BoF-RTGS) system. The payment transactions of these eight banks constitute over 90 per cent of total transactions in the BoF-RTGS system, in terms of value or number of transactions.

The time period of the payments is from 13-16 May 1997, which are the business days of a whole week excluding Monday. Although the four-day period is quite short, the week was characterized by most of the banks as representative of their normal payment patterns.

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[16] The participating banks were Aktia Savings Bank Ltd, Bank of Åland Ltd, Leonia Ltd (former Postipankki Ltd), Mandatum Bank Ltd (former Interbank Ltd), Merita Bank Ltd, Okobank, Skandinaviska Enskilda Banken Helsinki Branch and Svenska Handelsbanken AB, Branch Operation in Finland.

Payments to banks that were not included in the simulations were excluded from the data. This was done to keep the system closed and to prevent liquidity leakage. Payments relating to currency supply services were also excluded, for lack of data. The value of excluded transactions was small and their net effect virtually nil for the week studied.

In addition to the payments reported by the commercial banks, the payments of the Bank of Finland and certain nonbank entities were included.[17] Data on their payments was extrapolated from their settlement accounts at the Bank of Finland.

Table 7 gives the value and number shares of individual payment classes. For PMJ payments, only aggregate data were available from all the participating banks. The value and number breakdowns over different payment classes are summed up in table 8.

Table 7. **Outgoing payments (13- 16 May 1997)**

	Total value, mill. ECU	Total number of payments	Daily average value, mill. ECU	Daily average number of payments	Average value of payment, mill. ECU	Largest value of payment, mill. ECU
PMJ payments	2 389	2 467 979	597	616 995	0.001	n/a
POPS express transfers	3 685	1 905	921	476	1.9	84
POPS/PMJ cheques and bank drafts	1 812	9 877	453	2 469	0.2	140
Loro payments	18 707	3 711	4 677	928	5.0	585
Financial market transactions	7 363	344	1 841	86	21.4	938
Interbank transfers	6 475	251	1 619	63	25.8	316
Total	40 432	2 484 067				

Table 8. **Number and value shares of payment classes (13- 16 May 1997)**

Payment class	% of value	% of number
POPS express transfers	10	12
POPS/PMJ cheques and bank drafts	5	61
Loro payments	49	23
Financial market transactions	19	2
Interbank transfers	17	2

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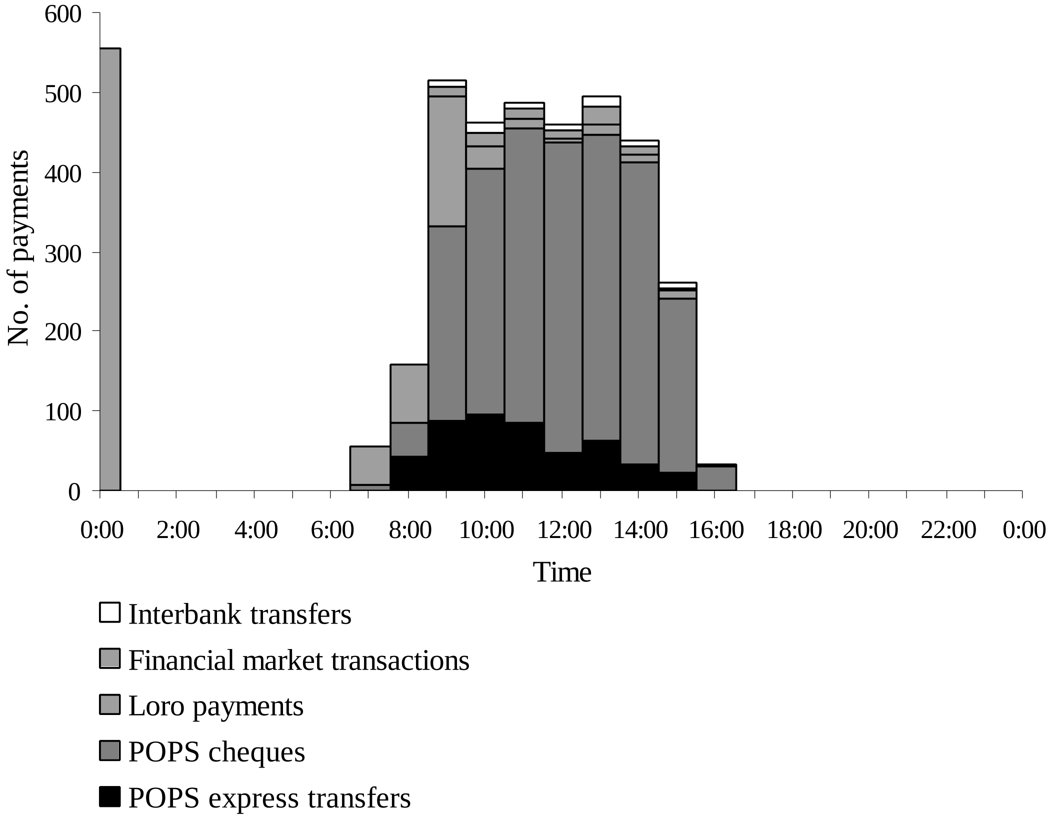
[17] These are the State Treasury, Finnish Export Credit Ltd (merged with Leonia Ltd), Finnish Central Securities Deporitory Ltd, SOM Ltd, Finnish Securities and Derivatives Exchange, Clearing House, and Helsinki Stock Exchange Ltd.

As we see from table 8, the bulk of the payments are POPS transfers and POPS cheques. These payments are mostly of small value and their share of the total value is relatively small throughout the day. The biggest payment group in terms of value is loro payments, which constitute almost half of the total value of outgoing payments. Other large payments are financial markets transactions and interbank transfers.

Regarding PMJ payments, only aggregate information on daily value and daily number of payments was available from all banks. Presently, these payments are settled via netting and there are no plans to change the practice. Thus data for these payment classes were used only to calculate bilateral net settlement positions.

The banks were asked to report all loro payments amounting to at least FIM 10 million (ECU 1.7 million) individually and smaller payments on an aggregate basis. In respect of payments worth less than FIM 10 million, total values and numbers were reported for each 20-minute period, as well as the daily breakdown of payment values.

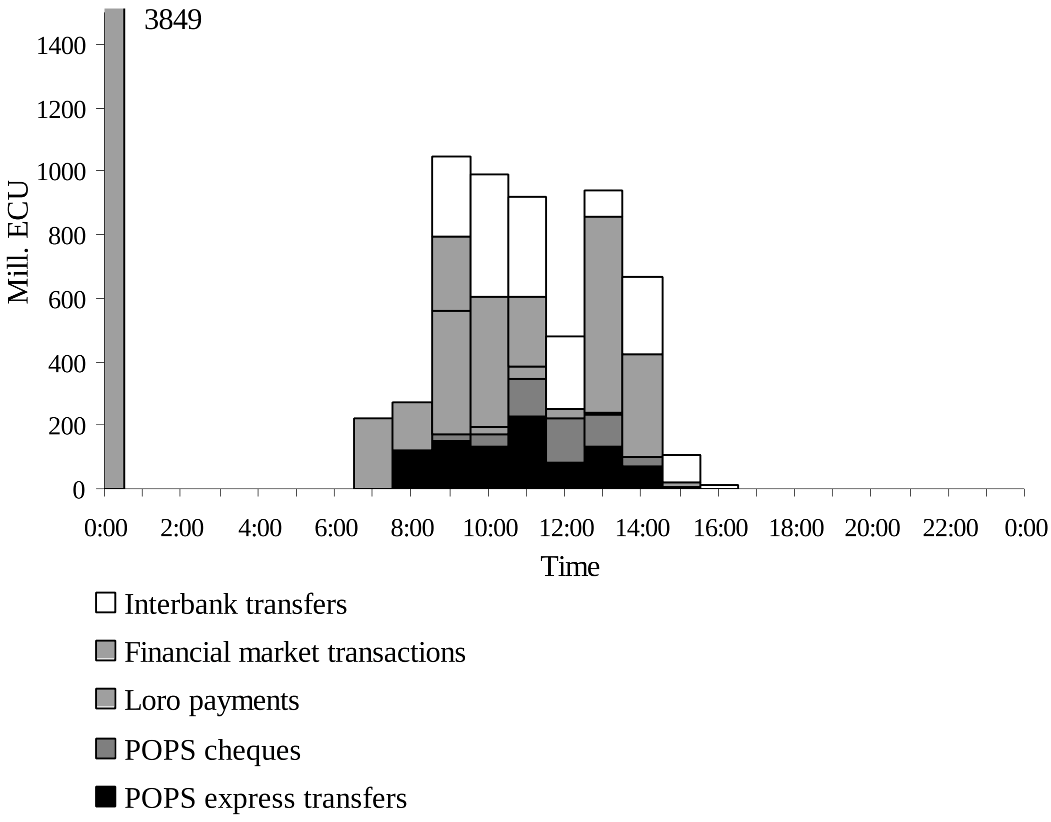
Figure 10. **Hourly breakdown of number of payments (daily averages, 13- 16 May 1997)**



The banks reported their POPS express transfers and cheques amounting to at least FIM 1 million (ECU 0.17 million) individually and smaller items on an aggregate basis for each 20-minute period. All financial market transactions and interbank transfers were reported individually.

The value and number breakdowns by payment classes and times during the day are given in figures 10 and 11. Payments reported as at the peak time, just after midnight, are those that have entered the system prior to their value dates. For the simulation runs, these payments are entered into the system before opening time.

Figure 11. **Hourly breakdown of the value of payments (daily average, 13- 16 May 1997)**



5.2.2 Generated data

Because a simulation period of four days is rather short for drawing conclusions about the effects of changes in the systems, a procedure had to be developed for extrapolating for additional days.

The characteristics of the generated data are the same as in the actual data in the following respects:

- the generated data consist of the same payment transactions as the actual data
- each account holder has the same transactions in both data sets because the generated data consist only of actual payments
- during each hour of the day, the same payment transactions occur.

The two data sets differ from each other in the following respects:

- the number of transactions in the generated data for a day is randomly chosen from a normal distribution with the same average and standard deviation as those of the actual recorded days
- the transactions of an account holder during a generated day is a subset of all the actual transactions of the account holder during the 4-day period
- the order of transactions is different, as the intrahour times for the transactions are randomly chosen for the generated data.

The number of transactions and their order is varied so as to determine whether the results are stable and whether the same settlement behaviour can be expected for days that differ slightly. The generation of additional days is explained in more detail in appendix 4.

5.2.3 Estimated TARGET transactions

The data on TARGET transactions is derived from balance of payment data, with certain assumptions added. Portions of both cross-border and loro payments will be settled in TARGET in Stage Three of EMU.

Cross-border payments

For cross-border payments (excl. loro payments), it is assumed that the proportions shown in table 9 will hold for the TARGET environment. Larger payments are assumed more likely to be settled via TARGET because they are more likely to be time-critical and hence more likely to be settled via RTGS. Moreover, quick settlement and the lack of risk in RTGS systems is more important for large-value payments. Assuming these proportions, the total number of payments came to about 200 per day and 50 000 per year. With these assumptions, altogether 22 per cent of all cross-border payments are settled via TARGET.

Table 9. **Estimated shares of cross-border payments to be settled in TARGET**

	% Number from all payments in group	Average daily number
< FIM 1 mill. (< ECU 0.17 mill.)	17.5	275
FIM 1-5 mill. (ECU 0.17-0.83 mill.)	35.0	57
> FIM 5 mill. (> ECU 0.83 mill.)	50.0	97

Because the payments did not have individual time stamps in the original data, each payment was stamped randomly according to the time distribution for all the payments. The payments in each value class shown in table 9 were randomly selected from the total collection of payments for each day. It was further assumed that the total number of cross-border payments remained unchanged.

Loro payments

Loro payments to/from outside of the euro area (63 per cent of the total number) are considered to remain as they are. For loro payments within the euro area (37 per cent), two scenarios were used. In the short-term scenario, 80 per cent of euro-area loro payments were converted into domestic payments and settled as POPS payments, 10 per cent were settled via TARGET and 10 per cent vanish. In the medium-term scenario (2–3 years), it is assumed that 40 per cent of the loro payments are converted into domestic payments, 50 per cent are settled as TARGET payments and 10 per cent vanish.

Table 10. **Scenarios for settlement of euro-area loro transfers in EMU**

	Settled in (% of total)		
	Pops	TARGET	VANISH
Short term -scenario	80	10	10
Medium term -scenario	40	50	10

For the short term, it is reasonable to assume that no major changes occur in payment practices. Prevailing methods are assumed to be used in general, and the new TARGET system is used only when it provides a new benefit (eg longer opening hours, same day settlement).

Certain kinds of payments will vanish because they will no longer be necessary, eg those related to currency trading with old euro area currencies. The single currency may also generate new kinds of payments, eg securities-trade-related payments, resulting from the elimination of foreign exchange risk. The net effect on the number of payments was assumed to be a 10 per cent reduction.

For the medium term, it can be assumed that payment practices will change and that banks will centralize their accounts for certain countries. Thus it was reasonable to assume that there are fewer of the former loro payments settled as POPS payments and that TARGET is used more extensively in the medium- term scenario than in the short-term scenario. The net effect of forces reducing and increasing numbers of payments was assumed to be a 10 per cent reduction compared to the RTGS-with-subnetting payment data.

For those loro payments that were transformed into TARGET payments, the sender/receiver was changed to the dummy bank ‘TARGET’. These changes were made so that the number of payments during a day to TARGET bank was about the same as the number of payments received from TARGET bank. Otherwise only the payment class of the existing euro-area loro transfers was changed.

Domestic payments

The numbers of domestic payments were assumed to remain unchanged. In the payment data used in the simulations, the four-day period is repeated 25 times in the 100 simulated days.

6 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. The indicators of liquidity usage and settlement delay are used for comparing the efficiency of the simulated systems.

6.1 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 12. 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.

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 theoretical lower bound (LB_t) for a bank's liquidity in an RTGS system with queuing, as explained in section 2.3.1.

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. In the Finnish payment settlement systems, net positions originating from net settlement systems must be settled immediately and some payments within an hour after entry into the system.[18] Thus it was necessary to simulate also a bank's real lower bounds for settlement systems with time-critical payments (LB_r). In these simulations each account holder was assigned a limit equivalent to its net position for all incoming and outgoing payments during the day. These limits were then raised as needed for timely settlement of time-critical transfers. The resulting minimum liquidity position for each account holder during the day represented the lower bound for its liquidity need.

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

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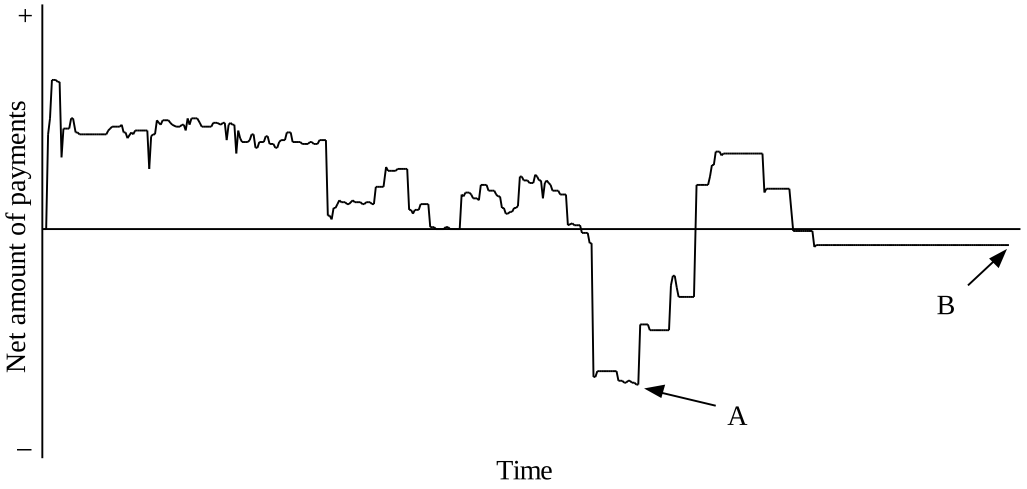
[18] Viz POPS-RTGS payments and POPS buckets.

system, preliminary simulations were run. 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_t). 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 12.

Because of payment prioritization, the real upper bounds for the pre-selected structures can differ from the theoretical bounds. In principle, these upper bounds (UB_r) should be the same as the theoretical bounds since, by definition, no queuing takes place, but a technical feature of the queuing of payments causes these bounds to differ. In all the simulations, payments are entered into the queue before the system opens and settlement begins. The prioritization of payments changes the settlement order and thus the upper bound. This subject is dealt in more detail in section 7.1.1.

Figure 12. **Intraday liquidity usege 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 13 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.

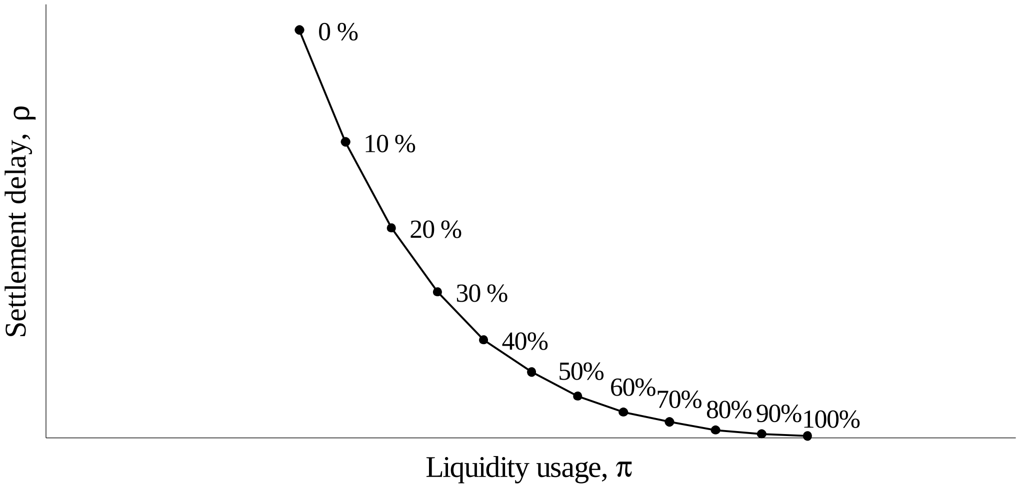
(4) $$LA_i = LB_i + LL * (UB_{t,i} - LB_{t,i})$$

Equation 4: Liquidity available, LA_i, for account holder i at a given liquidity level, LL (LB_t = theoretical lower bound, UB_t = theoretical 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 13 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. If the system were at any point to the right of the curve, at least some participants would have liquidity in excess of their upper bounds. This liquidity is unnecessary and could be removed without affecting the settlement of payments in the system.

Figure 13. **Relationship between a bank's settlement delay and liquidity usage in a payment system with various liquidity levels**



The different liquidity levels are presented as narrowing settlement delay intervals between the points on the curve. However, the simulations showed that distances between neighbouring points representing different combinations of liquidity usage and settlement delay can vary substantially. A small reduction in available liquidity may imply a big change in settlement delay and vice versa. Thus the effect of a change in banks' available liquidity depends not only on the shape of the curve but also on the distances between the different liquidity levels.

6.2 Settlement delay indicator

The indicator used for settlement delay in this study is called ρ (rho). The values of ρ range from zero to one and it is calculated for each account holder as shown in equation 5.

$$(5) \quad r = \frac{\sum_{i=1}^{T} Q_i}{\sum_{t=1}^{T} \sum_{i=1}^{t} V_i}$$

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

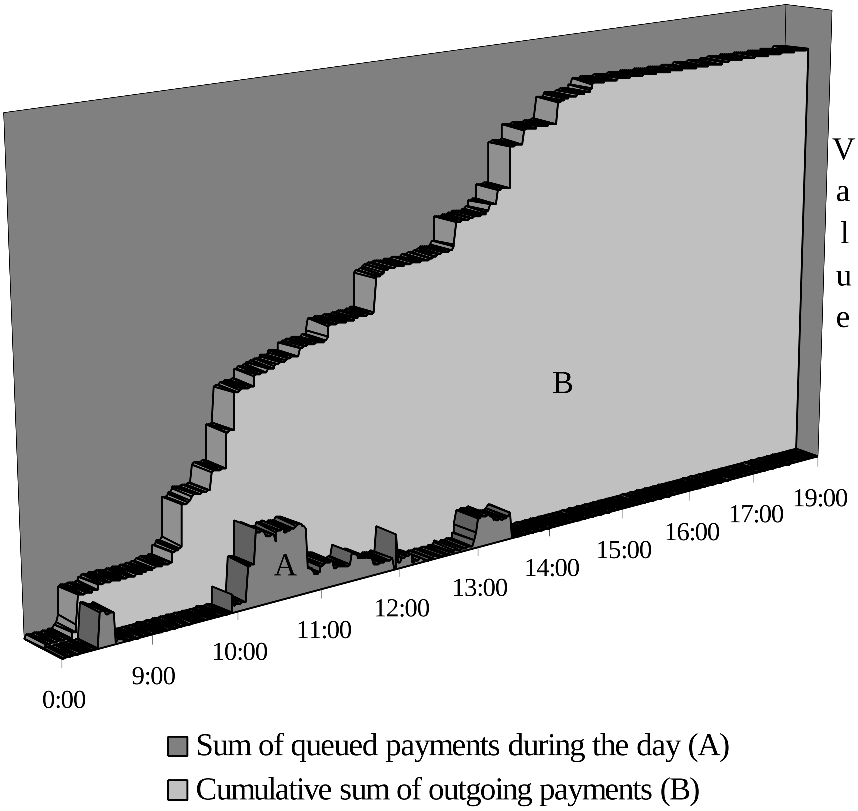
The numerator in equation 5 represents the sum of queues, ie the sum of the values of queued payments over each minute of the day. The denominator represents the sum of the cumulative values of outgoing payments over each minute of the day, and ρ is the ratio of the two.

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, ρ equals one. On the other hand, if the bank has an abundance of liquidity, all payments get settled immediately and ρ is zero.

The calculation of ρ is illustrated in figure 14. 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, r, is the ratio of A to B.

In calculating the system ρ, the numerator and denominator in equation 5 are summed up over all account holders in the system. The system ρ 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.

Figure 14. **Settlement delay indicator** r **= A/B**



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.

6.3 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 π (pi), is calculated for each bank as the ratio of its liquidity usage to the total value of its outgoing payments during the day. π ranges from zero to one. A π of zero means that there is no need for liquidity from outside the system, and if π equals one, liquidity is needed in the amount of the gross value of outgoing payments. π can also understood as the reciprocal of the turnover ratio.

$$(6) \quad p = \frac{LU}{\sum_{t=o}^{T} V_t}$$

Equation 6: Liquidity usage indicator, π, 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 π, 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' πs, where the weights are the banks' respective shares of the total value of payments.

7 Results from the simulations

Before explaining the results on the simulations, certain aspects of the data used in the simulations as well as certain assumptions that had to be made to enable comparisons between simulated systems require some explanation.

The time period for the actual payment data is rather short, ie only four days. Although not all payment system participants are included, the exclusions are unimportant in the sense that over 90 per cent of the payments in terms of value and numbers are included. The payments not included are those related to the maintenance of the currency supply and nullification of banks' post giro accounts. These payments are small or nil in net effect. There might still be some minor inaccuracies in the actual payment data. However, the inaccuracies were corrected to the extent possible so that the remaining errors should not be significant. The transformations made and reliability of the data are discussed in appendix 2. In the TARGET simulations, all TARGET transactions were estimated since, at the time of writing, no actual TARGET payment data were available. To compensate for this, two scenarios for the estimated TARGET transactions were employed.

It was further assumed in the model that the banks do not modify their payment settlement behaviour when the settlement structure changes. This assumption is needed because all simulation scenarios use the same payment data. Some behavioural changes are likely to occur in the real world in any shift from one settlement structure to another. The estimation of these changes is beyond the scope of this study.

In spite of these shortcomings, we believe the results of the simulations of the pre-selected payment system structures are quite accurate in absolute terms as regards the Finnish payment system as are the results of the simulations of optimization methods. As regards relative terms, we believe that all the results can be generalized. The shift from a payment settlement system based on netting to a system based on real-time gross settlement is likely to involve changes in liquidity usage and settlement delay similar to those found here. Neither should the relative effectiveness of the optimization methods vary across systems; only the absolute effectiveness might vary. To be sure of this, similar studies are needed with payment data from other countries.

7.1 Upper and lower bounds for liquidity

The theoretical and real upper bounds (UB_t, UB_r) and lower bounds (LB_t, LB_r) for liquidity presented in the sections 7.1.1 and 7.1.2 are the averages of the bounds for each of the account holders over the whole time period studied. The actual data covers payments made during the four-day period, and the 100 days of generated payment data are derived from the actual data.

The lower and upper bounds are calculated for all four preselected payment settlement structures. Theoretical lower and upper bounds do not take into account the time-criticalness of payments or queuing prioritization. All payments can be delayed until the end of the day. In the calculation of real lower and upper bounds, the time-criticalness of payments is taken into account as well as prioritization of payment classes.

7.1.1 Bounds with actual payment data

For the Hybrid, Advanced Hybrid and RTGS-with-queuing structures, the theoretical lower bound (LB_t) is the same (see table 11). This is because the theoretical lower bound is calculated from the same data as the net position at the end of the day. The difference between RTGS-with-subnetting and the other structures is due to the slight difference in the payment data used. The difference in the data is caused by the differences in opening times. Because the differences in data sets is insignificant and predictions concerning bank behaviour in settling payments are hard to make, the discrepancies in the data were not harmonized.

The theoretical upper bounds are also the same for the Hybrid, Advanced Hybrid and RTGS-with-queuing structures for the same reasons, ie they are calculated similarly with the same data. The difference between the RTGS-with-subnetting and the other structures is due to the slight difference in the payment data used.

The difference between the theoretical (LB_t) and real (LB_r) lower bounds is due to the introduction of time-criticalness and prioritization for some payments. The intraday credit limits were raised for some banks during the day, due to time-critical payments, which resulted in greater liquidity usage. The prioritization of payments changes the order in which the payments are settled and it can affect the liquidity usage negatively or positively for individual banks.

The difference between theoretical (UB_t) and real upper bound (UB_r) is due to differences between the structures and technical features of the systems. The theoretical upper bound (UB_t) is the minimum cumulative net position of incoming and outgoing payments over all points of time during the day, regardless of the structure used. In the pre-selected systems, the order in which payments are settled varies. The CNS system imposes liquidity needs on the RTGS system at different points of time during the day, depending on how many payments are settled. The TDNS system imposes liquidity needs on the RTGS system at the times when net settlements are due. These difference in the timing of liquidity needs causes the differences in the theoretical (UB_t) and real (UB_r) upper bounds.

Although liquidity equal to the theoretical upper bound level is sufficient for immediate payments settlement, technical features result in some queuing. With any of the structures studied, queuing occurs at the start of the day as payment orders that have arrived while the system was closed are entered into the system before start-up of the settlement process. The prioritization of payments may change the order in which payments are settled within this queue as compared to a pure FIFO rule and this can change the bounds.

Table 11. **Upper and lower liquidity bounds for pre-selected payment system structures, mill. ECU, actual payment data for 4 days, per bank average for n=8 banks**

	RTGS with subnetting	Hybrid	Advanced Hybrid	RTGS with queuing
Theoretical lower bound (LB_t)	53.4	53.1	53.1	53.1
Real lower bound (LB_r)	89.8	86.1	86.5	59.9
Theoretical upper bound (UB_t)	225.4	225.4	225.4	225.4
Real upper bound (UB_r)	158.2	229.7	229.7	222.1

Table 12. **Ratio of real to theoretical bounds, %, actual payment data for 4 days**

	RTGS with subnetting	Hybrid	Advanced Hybrid	RTGS with queuing
Theoretical lower bound (LB_t)	100.0	100.0	100.0	100.0
Real lower bound (LB_r)	168.1	162.2	163.0	112.9
Theoretical upper bound (UB_t)	100.0	100.0	100.0	100.0
Real upper bound (UB_r)	70.2	101.9	102.3	98.5

In terms of real lower bounds (LB_r), the RTGS-with-queuing structure requires the least liquidity, and there are no significant differences between other structures in this respect. The RTGS-with-queuing structure is the only one of the pre-selected structures not including time-critical payments. The introduction of time-criticalness and prioritization of some payments[19] seems to significantly increase a bank's lower bound of liquidity need in all the structures.

In terms of real upper bounds (UB_r), the RTGS-with-subnetting structure requires the least liquidity. This suggests that this structure is the most efficient in terms of liquidity needs for settling payments without queuing in an RTGS system. However, it should be noted that all structures other than RTGS-with-queuing included one or more net settlements and that settlement delay in these TDNS systems is not taken into account in the calculations. As the payments are collected for the net settlement, their final settlement is postponed until the net positions are settled between the banks.

Moreover, the differences between lower and upper bounds are quite significant, both in theoretical and practical terms. The simulations show that if the banks choose to settle their payments immediately without queuing, they will need more liquidity than that required for end-of-day settlement of net positions. The RTGS-with-subnetting structure required only 1.8 times the amount of liquidity that is required for immediate settlement, compared to a ratio of 2.7 for both hybrid structures and about 3.7 for the RTGS-with-queuing structure. Corresponding indicators for liquidity usage and settlement delay are summarized in table 13.

Table 13. **Settlement delay and liquidity usage for real lower and upper liquidity bounds, %, actual payment data for 4 days**

	Real lower bound (LB_r)		Real upper bound (UB_r)	
	Liquidity usage, π	Settlement delay, ρ	Liquidity usage, π	Settlement delay, ρ
RTGS with subnetting	27	19	37	0
Hybrid	9	18	25	0
Advanced Hybrid	9	17	25	0
RTGS with queuing	6	29	21	0

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[19] viz POPS payments, POPS buckets and net settlement transactions.

The RTGS-with-queuing structure requires the least liquidity if there is no queuing. The RTGS-with-subnetting structure is the least efficient structure in this respect. The Hybrid and Advanced Hybrid structures are between the former structures, assuming equal liquidity usage.

The RTGS-with-queuing structure is also superior in terms of liquidity usage in situations with maximal queuing. The cost of the reduction in liquidity usage is more settlement delay. The Hybrid and Advanced Hybrid structures use slightly more liquidity but have substantially shorter settlement delays. Liquidity usage with the RTGS-with-subnetting structure is reduced by only 10 percentage points compared to the situation with no settlement delays. This structure uses the largest amount of liquidity relative to the value of payments settled.

It can be concluded that the RTGS-with-queuing structure would be the superior option for the banks in terms of liquidity needs and liquidity usage. However, within the lower levels of liquidity (ie at the lower bound level), the RTGS-with-queuing structure results in long delays in settlement. The Hybrid and Advanced Hybrid structures can be seen as good compromises between liquidity usage and settlement delay. In both structures, some of the payments were settled via netting, and the delay in settling these payments is not taken into account here. The system in which the majority of payments was settled via netting was not as good as the other pre-selected systems in terms of efficiency. The circulation speed of liquidity in the RTGS system was very low, only 2.7 at the upper bound of liquidity and 3.7 at the lower bound.[20]

7.1.2 Bounds with generated payment data

The results were quite stable over the variations on settlement order and number of daily transactions. The simulations with the generated payment data supported the conclusion drawn on the basis of four days of actual payment data. Even though the RTGS-with-queuing structure may be the superior structure at higher levels of liquidity, the Hybrid and Advanced Hybrid structures are good compromises between liquidity usage and settlement delay. The simulations with generated data resulted in only minor differences between the different structures.

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[20] The circulation speed of liquidity is the reciprocal of system π, ie the ratio of total value of payments to liquidity usage during a day.

The lower bounds were higher with the generated payment data than with the actual data. This suggests that the variation in the value of incoming transfers is greater than the value of outgoing transfers. Also the upper bounds are higher, indicating some deterioration in payments synchronization during the day. However, the results are in line with the actual payment data;

Lower bounds of liquidity:

- Time-criticalness and prioritization of payments increased liquidity needs significantly. This can be seen in table 14 as the difference between the theoretical and real lower bounds in all of the structures.
- The RTGS-with-queuing structure required the least liquidity, both in absolute and relative terms. This was due to the lack of time-critical transfers originating from net settlement systems and higher numbers and values of payments in the RTGS system.
- The settlement delay was smallest with the Hybrid and Advanced Hybrid structures, as shown in table 16. These are the systems that included optimization methods.
- The RTGS-with-subnetting structure required the most liquidity relative to the total value of payments settled. Also the settlement delay was greatest in this structure. In absolute terms, there were no significant differences between the different structures.

Upper liquidity bounds:

- The time-criticalness and prioritization of payments reduced the liquidity need in the RTGS-with-subnetting structure, apparently because the net settlements evened out the payment flows. In other structures, the effects were minimal.
- The RTGS-with-subnetting structure required the least liquidity in absolute terms. The differences between the other structures were insignificant. Relative to the value of payments processed via RTGS, the RTGS-with-queuing system used the least liquidity.

Table 14. **Upper and lower liquidity bounds for pre-selected payment system structures, mill. ECU, generated payment data, average for n=8 banks**

	RTGS with subnetting	Hybrid	Advanced Hybrid	RTGS with queuing
Theoretical lower bound (LB_t)	134.3	134.6	134.6	134.6
Real lower bound (LB_r)	151.7	156.3	156.1	139.4
Theoretical upper bound (UB_t)	236.4	236.3	236.3	236.3
Real upper bound (UB_r)	208.0	237.5	237.4	236.3

Table 15. **Ratios of real bounds to theoretical bounds, generated payment data, 100 days, %**

	RTGS with subnetting	Hybrid	Advanced Hybrid	RTGS with queuing
Theoretical lower bound (LB_t)	100.0	100.0	100.0	100.0
Real lower bound (LB_r)	112.8	116.2	116.0	103.6
Theoretical upper bound (UB_t)	100.0	100.0	100.0	100.0
Real upper bound (UB_r)	88.0	100.5	100.4	100.0

The values of the liquidity usage indicator, π are significantly higher with the generated payment data and the settlement delay indicator, ρ is lower in all pre-selected structures. However, relative to each other, the differences between the structures are not substantial. The Advanced Hybrid structure is superior in terms of settlement delay and the RTGS-with-queuing structure in terms of liquidity usage. The difference between the Advanced Hybrid and Hybrid structures is only 1 percentage point by both indicators.

Table 16. **System settlement delay and liquidity usage at the real lower and upper liquidity bounds, generated payment data, 100 days, %**

Structure	Real lower bound		Real upper bound	
	Liquidity usage, π	Settlement delay, ρ	Liquidity usage, π	Settlement delay, ρ
RTGS with subnetting	42	12	58	0
Hybrid	18	6	27	0
Advanced Hybrid	17	5	26	0
RTGS with queuing	15	7	25	0

7.1.3 Main results

The liquidity need increased for all the systems when RTGS transfers were settled immediately without queuing instead of by netting at the end of the day. Compared to the latter, liquidity usage for an average day ranged from 47 per cent higher for the RTGS-with-subnetting structure to 88 per cent higher for the RTGS-with-queuing structure. For both Hybrid structures, usage was about 65 per cent higher.

The tradeoffs between liquidity usage and settlement delay were found to be fairly restricted. In the RTGS-with-subnetting structure, liquidity usage equal to about 10 per cent of the daily gross value of payments could be saved via queuing. With other structures, liquidity usage could be reduced by about 15 per cent of the total value of payments.

In terms of liquidity usage alone, the RTGS-with-queuing structure appeared to be superior. However, at low levels of liquidity, the RTGS-with-queuing structure entailed longer settlement delays than the Hybrid systems. In the hybrid structures, the settlement delay was slightly shorter but they used somewhat more liquidity. Thus the Hybrid and Advanced Hybrid structures can be considered good compromises between liquidity usage and settlement delay at all liquidity levels. For the RTGS-with-subnetting structure, liquidity needs and settlement delay were the greatest. Additionally the settlement delay of payments settled in the net settlements was not taken into account.

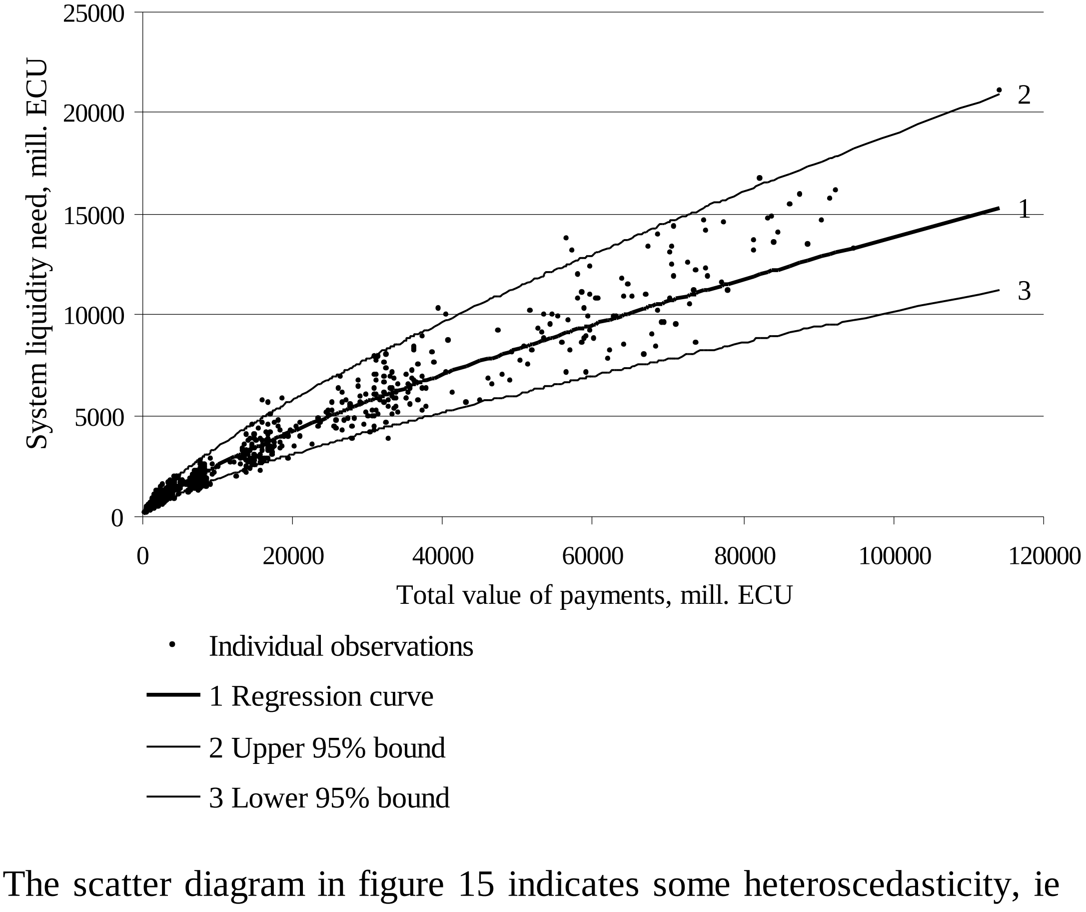
7.2 Total daily value of payments and liquidity need

A system's liquidity needs are largely determined by the periodic total value of payments settled in the system. The settlement procedures themselves also affect liquidity needs, but to a lesser extent. To quantify the effects of daily payments value on the amount of liquidity needed for immediate settlement, simulations were run in which all factors other than daily payments value were kept constant. The simulations were run using generated payment data with the number of payments being 1/8 , 1/4 , 1/2 , 2, 4 and 8 times the number in the original data. The effects of daily payments value were studied for two structures: RTGS-with-queuing and Hybrid. Using these structures, we studied the aggregate liquidity need for the payment system as a function of the value of payments settled.

7.2.1 RTGS with queuing

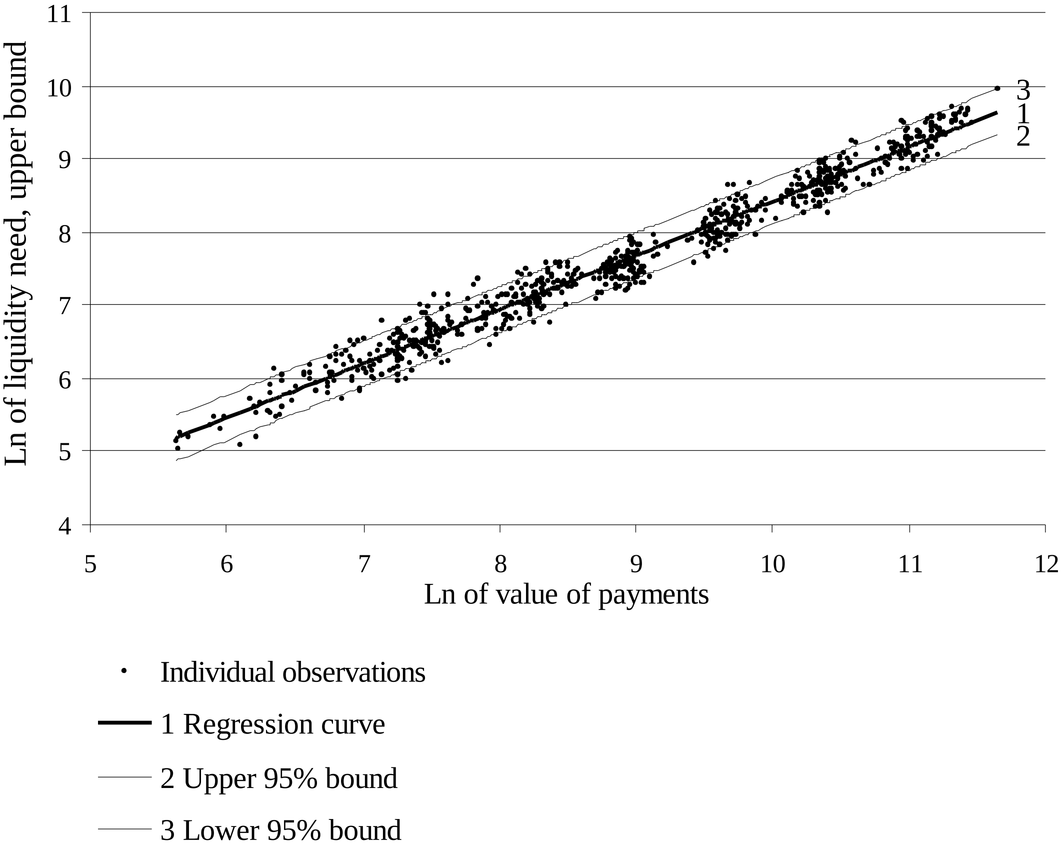
The scatter diagram in figure 15 shows the daily values of payments settled and corresponding liquidity needed for immediate settlement in individual simulation runs. The two variables are very highly correlated (correlation coefficient approx. 98 per cent). The relationship is slightly loglinear, especially at low aggregate settlement values. At higher values of payments, the relationship can be considered as approximately linear. With large daily payment values, the law of large numbers begins to have an effect and the marginal liquidity need remains more stable.

Figure 15. **Relationship between system upper bound of liquidity need and daily value of payments in RTGS-with-queuing structure, n=700**



The scatter diagram in figure 15 indicates some heteroscedasticity, ie the variance of the distribution of liquidity need tends to increase as daily payments value increases. The heteroscedasticity disappears when logs are used. The transformed scatter diagram with the estimated regression line and 95 per cent confidence intervals are shown in figure 16.

Figure 16. **Relationship between system liquidity need and value of payments, logarithmic scale, n=700**



The estimated regression line in its linear form is presented in equation 7 and in its exponential form in equation 8. The fit is exceptionally good; the value of R-squared, ie the percentage of variation in the liquidity need that can be explained by the variation in the daily value of payments, is 97 per cent. The R.M.S error of the regression line is 0.19 and, as the residuals are normally distributed, the 95 per cent confidence intervals (shown in figures 15 and 16) can be calculated.

(7) $\ln(UB_r) = b * \ln(V) + I + e$

Equation 7: Regression curve in linear form for the system upper bound of liquidity in the RTGS-with-queuing structure as a function of daily value of payments settled (UB_r = upper bound of liquidity, V = value of payments, I = intersect, ε = error term)

(8) $UB_r = V^b * e^{I+e} = V^{0,739} * e^{1,025+e}$

Equation 8: Regression curve in exponential form for the system upper bound of liquidity in the RTGS-with-queuing structure as a function of daily value of payments settled

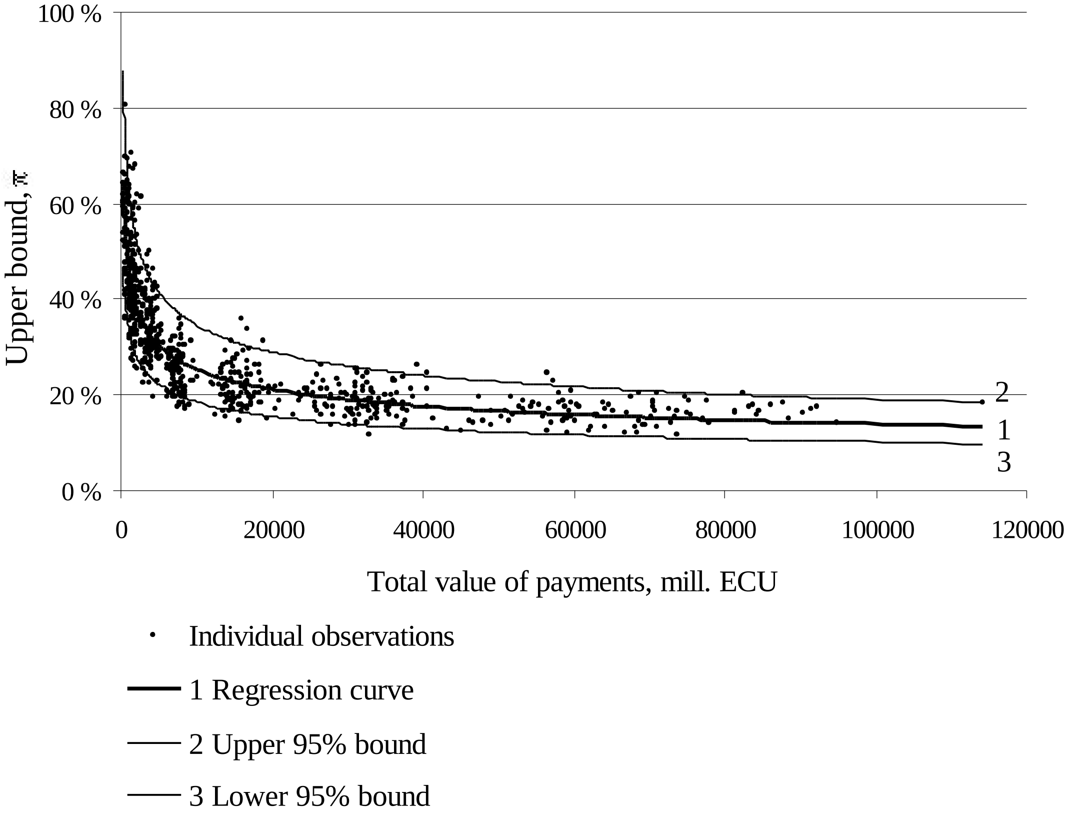
The relationship between π and daily value of payments is depicted in figure 17 (π represents the amount of liquidity used for settlement as a share of the total value of payments, as explained in section 6.3). The value and variance of π decrease as the daily value of payments increases. As daily payments value increases, the incoming and outgoing transfers more evenly offset each other during the day and so less liquidity per value sent is needed. Moreover, the ‘shock effect’ of large payments on liquidity requirements is reduced, as their share in the total value of payments diminishes.

The mathematical formulation of the regression curve is illustrated in equation 9. From the equation we can see that π approaches zero asymptotically as the value of payments approaches infinity. The slope of the curve is very modest at high values of payments. The total value of payments should be 30 times bigger than the prevailing value of payments in October 1998 in order for π to be below 10 per cent on average.

(9) $p = \frac{UB_r}{V} = \frac{V^b * e^{I+e}}{V} = V^{-0,261} * e^{1,025+e}$

Equation 9: The regression curve for predicting system π from the value of payments settled

Figure 17. **Relationship between system p and daily value of payments, n=700, mill. ECU**



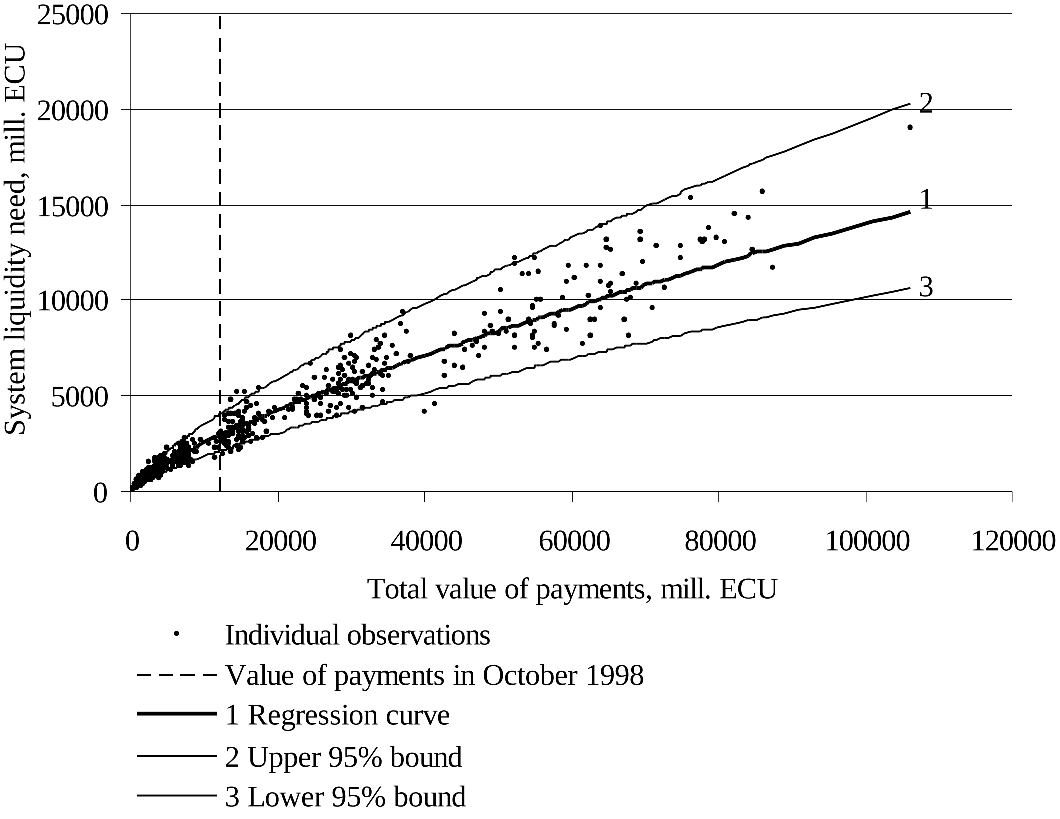
At low values of payments, chance plays a bigger role and the variation in the liquidity need is greater than with higher values of payments. At very low payments values, the liquidity need of the system can reach up to 90 per cent of the gross value of payments. At very high values of payments, the system liquidity need is more predictable and much lower in relative terms.

7.2.2 Hybrid structure

The Hybrid structure was simulated with the same payment data. Because payments in the Hybrid structure are settled not only in the RTGS system but also in the POPS system and in two net settlements, the payment flow in the RTGS system is somewhat different than in the case of RTGS with queuing. In this structure, prioritization of payments is also accounted for, and some transfers are considered to be time-critical. In this section the Hybrid structure is analysed for its liquidity needs in the RTGS system where net settlement transactions from other payment systems are included.

The results on the Hybrid structure are very similar to those from the simulations on the RTGS-with-queuing structure. The relationship between liquidity need for immediate settlement and value of payments settled is shown in figure 18.

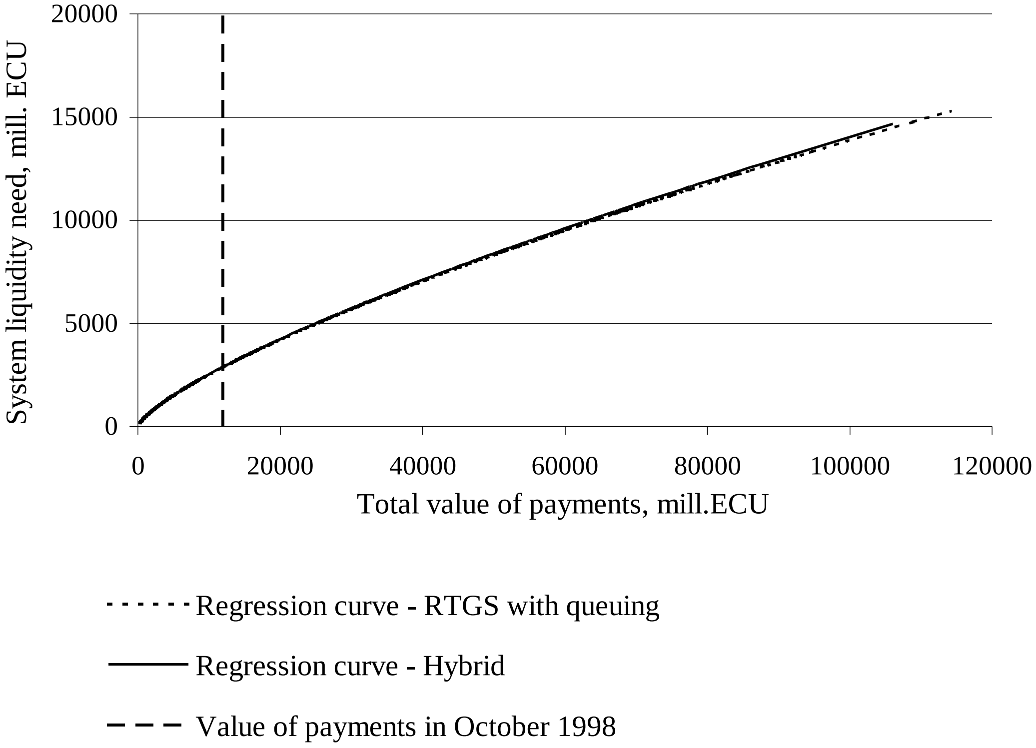
Figure 18. **Relationship between daily value of payments and system upper bound of liquidity need, Hybrid structure, n=700**



R-squared value for the regression curve was as good as in the case of RTGS with queuing, approximately 97 per cent. The R.M.S error of the regression line was slightly higher, approximately 0.20, and thus the confidence interval was slightly wider.

The regression curves for both systems are shown in figure 19. The curve representing the liquidity need of the RTGS-with-queuing structure is lower at payment values in excess of ECU 1 824 million whereas the Hybrid structure uses less liquidity at lower values of payments settled. However, the differences are very marginal. In the Hybrid structure, the time-criticalness of some payments increased the system liquidity need, but the liquidity optimization feature of netting the queued transfers was also used. As the value of payments flowing through the RTGS system was lower in the Hybrid structure, its curve in figure 19 is shorter. The mathematical formulation of regression curve for the Hybrid structure is defined in equation 10.

Figure 19. **Relationship between value of payments and system upper bound of liquidity need RTGS-with-queuing and Hybrid structures**



(10) $UB = V^{b} * e^{I+e} = V^{0,742} * e^{1,002+e}$

Equation 10: System upper bound for liquidity in the Hybrid structure as a function of the value of payments settled

The average daily value of payments settled in the Finnish RTGS ystem for October 1998 was ECU 11.9 billion and is shown as a vertical line in figure 19. According to the regression curve for the Hybrid structure, the liquidity needed for immediate settlement of this amount would be ECU 2.89 billion on average and, on 95 per cent of the days, the need would be less than ECU 3.95 billion. The actual and estimated liquidity needs are summarized in table 17. The estimates assume that the liquidity is optimally distributed among the participants.

In October 1998 intraday credit extensions for the banks participating in the BoF-RTGS totalled ECU 3.16 billion, the required reserves available for settlement purposes ECU 0.86 billion and excess reserves ECU 0.05 billion, giving a total of ECU 4.07 billion. If all liquidity available for the banks were optimally distributed, queuing would take place only on a few days out of a hundred, according to the estimate.

Table 17. **Actual and estimated liquidity needs, bill. ECU**

Liquidity in October 1998		
Intraday credit limits	3.16	
Required reserves	0.86	
Excess reserves	0.05	
Total	4.07	
Estimated liquidity need		
	RTGS with queuing	Hybrid
Average	2.89	2.90
95% of days under	3.95	4.01
99% of days under	4.49	4.58

7.3 Simulations of pre-selected payment system structures

The results presented here concern only the banks that participated in the simulations, not the other participants in the BoF-RTGS system. It should also be noted that these results are averages for the whole banking sector and for the whole time period simulated and hence, for individual banks and days, the situation could be quite different.

7.3.1 RTGS-with-subnetting vs Hybrid structure

7.3.1.1 Simulations with actual payment data

The adequacy of existing credit limits

The standard deviation of banks' intraday net balances is larger for the Hybrid structure than for the RTGS-with-subnetting structure. The larger standard deviation suggests that the time-distribution of incoming and outgoing payments is less balanced with the Hybrid structure than with the RTGS-with-subnetting structure (see appendix 1, table 1).

With the Hybrid structure, the need for intraday credit is significantly greater for the whole banking sector as well as for some individual banks. The extent of queuing is also somewhat greater with the Hybrid structure. On average, 10 payments were queued daily for an average time of 45 minutes. The longest queuing time was about

3 hours. This suggests that on average the existing intraday credit limits are sufficient but that in some cases extra intraday credit or other extra liquidity might be needed (see appendix 1, tables 3 and 4).

The average value of a queued payment in the Hybrid structure was however relatively low, ie about ECU 21.4 million, and the average aggregate value of a payment queue was asbout ECU 43.8 million, suggesting little need for extra liquidity. Moreover, the number of queued payments was very low, ie 2.2 on average for times when there were queues. The most payments in a queue at one time was 15, with a total value of ECU 204.5 million (see appendix 1, table 5). With the RTGS-with-subnetting structure, which does not entail queuing, only two payments could not be settled immediately and were re-entered into the system at the earliest possible settlement time.

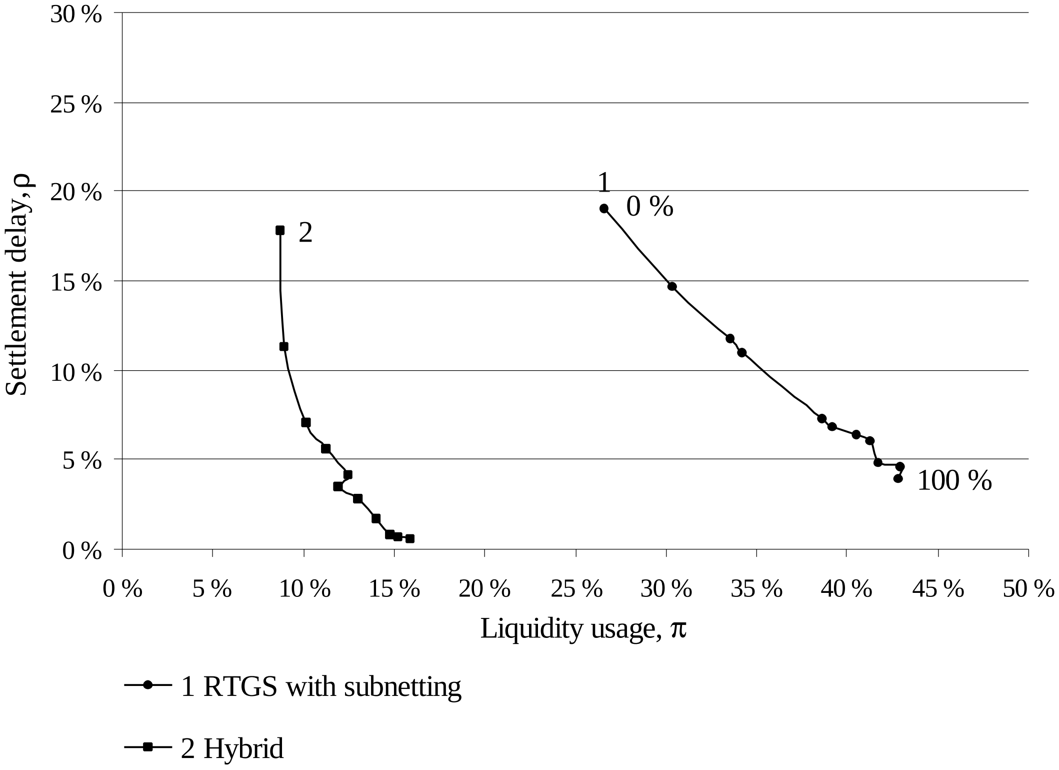
Efficiency comparison of the Hybrid and RTGS-with-subnetting structures

The relative efficiency of RTGS settlement as between the RTGS-with-subnetting and Hybrid structures is shown in figure 20. The curves are based on the different available liquidity levels (0 to 100 per cent, ie from theoretical lower to upper bound) and show the liquidity usage relative to the value of outgoing payments (π) and corresponding settlement delay (ρ). The Hybrid structure uses only about a third as much liquidity for a given value of payments and given settlement delay time compared to the RTGS-with-subnetting structure, and is thus much more efficient.

The theoretical system upper bound (UB_t) for the RTGS-with-subnetting structure (ie 100 per cent of the level of liquidity) results in liquidity usage amounting to about 43 per cent of total value sent. The real upper bound (UB_r) results in liquidity usage of about 37 per cent, as was shown in table 13 on page 57. For the Hybrid structure, the corresponding figures are about 16 per cent and 22 per cent.

The curve for the Hybrid structure is concave between available liquidity levels of 30 per cent and 50 per cent, which means that reductions in available liquidity result in queuing at critical points of time during the day and the banks are forced to raise their intraday credit limits in order to settle time-critical transfers. The rise in the limits is greater on average than the reduction in liquidity usage due to the use of lower intraday credit limits. The same kind of concavity can be seen with the RTGS-with-subnetting structure between the liquidity levels of 80 per cent and 100 per cent. This topic was discussed earlier in section 2.3.2.

Figure 20. **Relationship between system settlement delay (r) and liquidity usage (p) in RTGS-with-subnetting and Hybrid structures, actual payment data, 4 days**



Another interesting result is that the curve for the Hybrid structure is almost vertical between the two lowest levels of available liquidity (0 and 10 per cent), and between other levels of liquidity the curve is quite steep. This suggests that the selection of a lower liquidity level will not significantly reduce liquidity usage but will result in a significant increase in settlement delay.

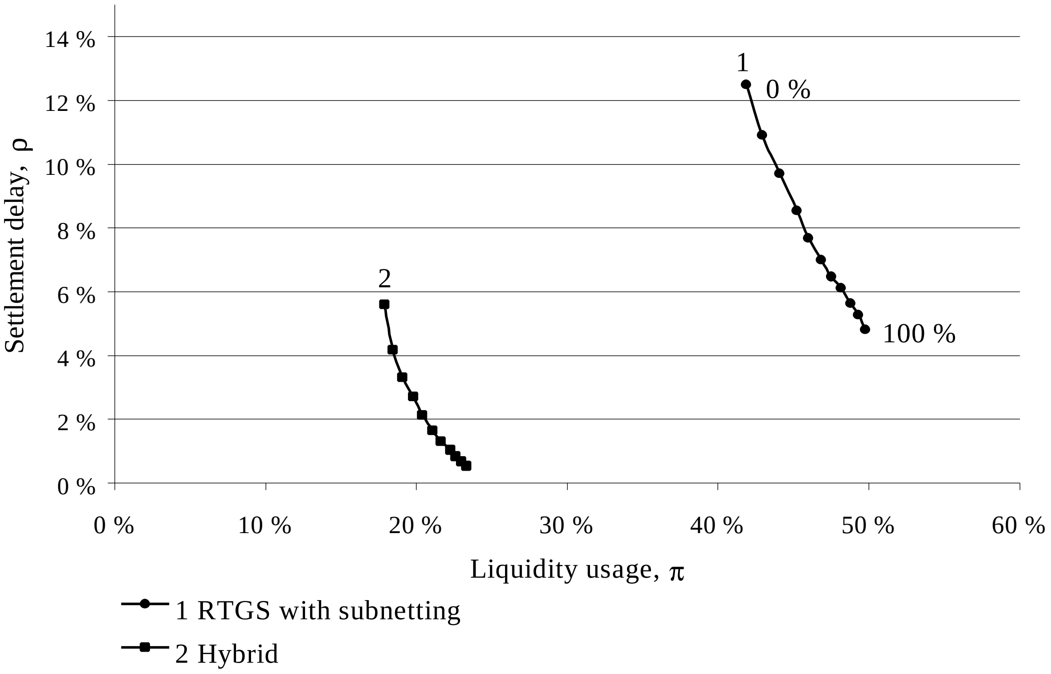
The differences in the features of the two structures can explain the significant difference in performance. In the RTGS-with-subnetting structure, the number of transactions is low but their average value is high. The transactions consist mainly of large-value transfers settled via RTGS and settlements of net positions originating from net settlement systems. Because the individual transfers are large and the number of payments small, the liquidity need relative to the value of payments flowing through the system is larger with the RTGS-with-subnetting structure than with the Hybrid structure.

There is no queuing or optimization routine in the RTGS-with-subnetting structure. In the Hybrid structure the netting of queues reduces liquidity usage by solving gridlocks during the day and by possibly clearing at the start of the day any queues awaiting the opening of the system.

7.3.1.2 Simulations with generated payment data

Only the efficiency of the pre-selected settlement structures is studied with generated payment data. The adequacy of limits could not be studied since actual limits and balances were not available for the 100 generated days.

Figure 21. **Relationship between system settlement delay (r) and liquidity usage (p) in RTGS-with-subnetting and Hybrid structures, generated payment data, 100 days**



The results from the simulations with generated payment data support the conclusions drawn in the previous section. The Hybrid structure is much more efficient than the RTGS-with-subnetting structure in terms of liquidity usage and settlement delay at all liquidity levels.

For the Hybrid structure, the settlement delay is less and the liquidity usage slightly greater with the generated payment data than with the actual payment data. And for the RTGS-with-subnetting structure, the settlement delay at lower levels of available liquidity is slightly less and the liquidity usage less with the actual payment data than with the generated data. This can be explained by the fact that, over a longer period, the variation of individual observations is smaller. For the same reason, there are no concave sections in the curves for the RTGS-with-subnetting and Hybrid structures based on actual payment data.

It is noteworthy that the peak liquidity usage as measured by π, reached in the RTGS-with-subnetting structure 73 per cent on one of the 100 days simulated. For the Hybrid structure the peak liquidity usage during the period was only 35 per cent of the total value of outgoing payments. By contrast, the peak settlement delays were fairly similar in the two systems, about 30 per cent. This indicates that in the RTGS-with-subnetting structure, with a small number of large-value payments, the liquidity need may on certain days approach the gross value of transfers.

7.3.2 Hybrid vs Advanced Hybrid structure

7.3.2.1 Simulations with actual payment data

The adequacy of existing credit limits

Differences between the Hybrid and Advanced Hybrid structures (structures 2 and 3) are very small. Differences in standard deviation of balances and average limit usage are insignificant (see appendix 1, tables 1 and 2).

With the Advanced Hybrid structure, average queuing time was lower (in two of the three days with queuing) and aggregate value of queued payments slightly lower, whereas the average number of queued payments was 4.5 compared to 2.2 for the Hybrid structure (see appendix 1, tables 3 and 4). This is due to the payments splitting in the Advanced Hybrid structure. The peak queuing time is the same for the Hybrid and Advanced Hybrid structures.

The netting of the queues every 20 minutes had only minor effects on liquidity needs and settlement delay, as it succeeded only once, at the start of day. The splitting of payments enhanced the use of existing liquidity to some extent and reduced the average value of queued payments while increasing the number of queued payments.

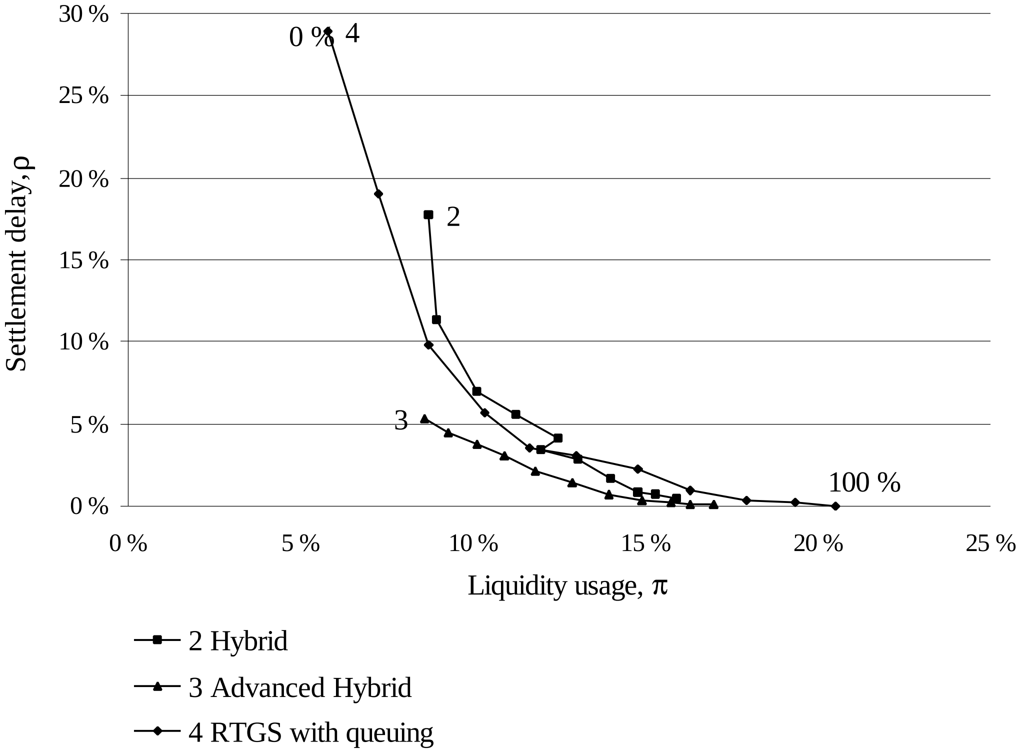
The RTGS-with-queuing structure does not differ much from the other two structures. In terms of average usage of intraday credit limits and queuing times, this structure was superior on two days and inferior on the two other days. However, the differences were small. In terms of number and average value of queued payments, the performance of the RTGS-with-queuing structure was in between the Hybrid and Advanced Hybrid structures. On the other hand, the queues for the RTGS system represented higher value than for the other structures. The average value of a queue was about three to four times that for the Hybrid or Advanced Hybrid structure. Also, the peak value of a queue during the simulation period was about twice as high, ECU 459.5 million (see appendix 1, table 5).

Efficiency comparison of the Hybrid, Advanced Hybrid and RTGS-with-queuing structures

The relative efficiencies of the Hybrid, Advanced Hybrid and RTGS-with-queuing structures are illustrated in figure 22.

The Advanced Hybrid structure is superior from the banks perspective at all liquidity levels vs the other two structures. This suggests that, compared to the Hybrid structure, settling within-limit POPS payments on a gross basis instead of netting them continuously increases system liquidity. However, the differences are small and hence it is safer to say that executing all POPS payments on a gross basis will not cause additional liquidity restraints vs the Hybrid structure, at least when payment splitting is used as a liquidity optimization method. The splitting of payments apparently reduced settlement delay significantly.

Figure 22. **Relationship between system settlement delay (r) and liquidity usage (p) for RTGS-with-queuing, Hybrid and Advanced Hybrid structures, actual payment data, 4 days**



On the other hand, the two PMJ clearings in the Advanced Hybrid structure seem to level off the peaks in interbank payment flows and thus reduce liquidity usage at high available liquidity levels vs the RTGS-with-queuing structure.

At lower levels of available liquidity the RTGS-with-queuing structure uses the least liquidity of all the pre-selected payment system structures but at the cost of having clearly the most settlement delay. The RTGS-with-queuing structure also uses the most liquidity at the nonqueuing liquidity level.

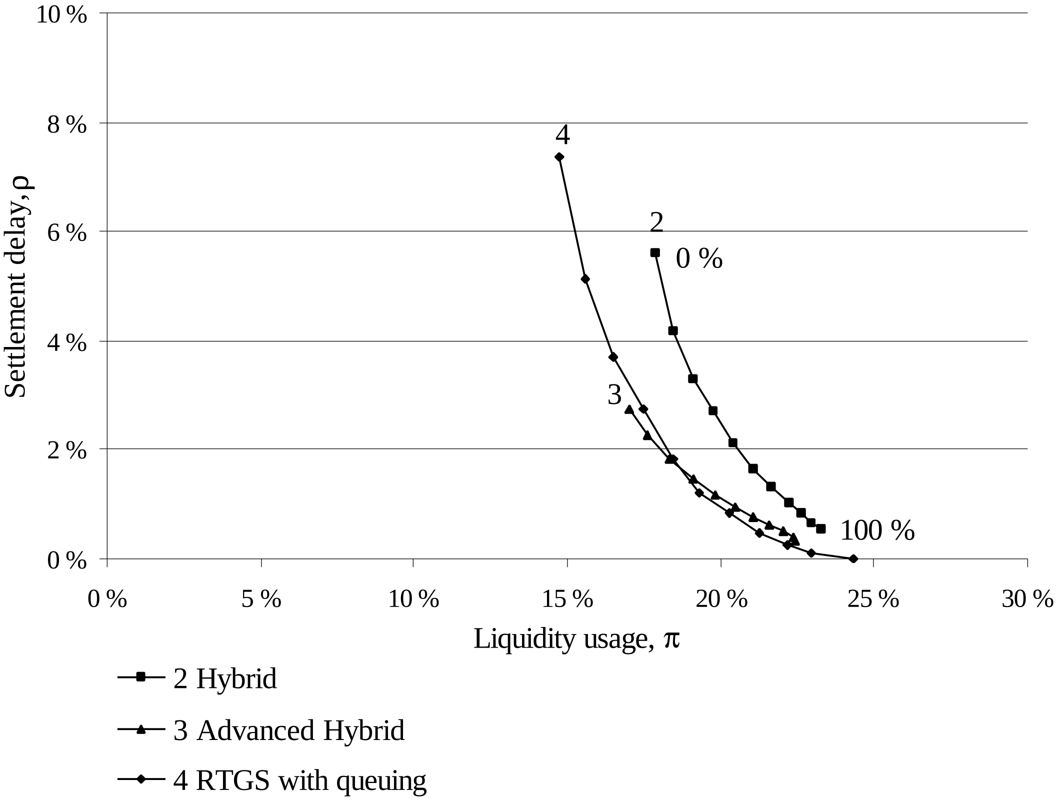
Otherwise the differences between these structures are relatively small. It is noteworthy that the curves for the Hybrid and RTGS-with-queuing structures cross between liquidity levels of 50 per cent and 60 per cent. This suggests that if the banks select higher available liquidity levels, the Hybrid structure will be more cost-effective, whereas if they choose lower levels, the RTGS-with-queuing structure will be more cost-effective.

7.3.2.2 Simulations with generated payment data

The results from the simulations with generated payment data do not differ significantly from those with actual data. The Advanced Hybrid and RTGS-with-queuing structures seem to be the superior structures, the former at low levels of available liquidity and the latter at high levels. The Hybrid structure is always inferior to the other two structures. The curves have shifted to the right and the settlement delay has decreased to some extent compared with the simulations with actual payment data. Moreover, there is no longer a concave section in the curve for the Hybrid structure.

The reasons for this may be that with more observations the variation is smaller and that there is less synchronization of payments with the generated payment data. But this also suggests that over the longer run the RTGS-with-queuing structure, especially the Advanced Hybrid version, might be the most cost-effective structure for the banks.

Figure 23. **Relationship between system settlement delay (r) and liquidity usage (p) in RTGS-with-queuing, Hybrid and Advanced Hybrid structures, generated payment data, 100 days**



Using the generated data, the curves for the Advanced Hybrid and RTGS-with-queuing structures again intersect. The Advanced Hybrid structure fared better at low liquidity levels, albeit the system could not operate on as little liquidity as the RTGS-with-queuing structure. At high levels of available liquidity the RTGS-with-queuing structure resulted in less delays in settlement.

7.3.3 Simulations on the effect of TARGET transactions

The simulations on TARGET transactions were done with the Hybrid structure in order to determine the effects of TARGET on the Finnish interbank payment system as at the start of Stage Three of EMU.

The simulations were divided into short- and medium-term scenarios, as explained in section 5.2.3. Only the upper and lower bounds for liquidity were studied.

Table 18. **Upper and lower liquidity bounds for the Hybrid structure, with and without TARGET transactions, mill. ECU, generated payment data, 100 days, average for n=8 banks**

	Without TARGET	TARGET: short-term scenario	TARGET: medium-term scenario
Theoretical lower bound (LB_t)	134.6	112.8	133.4
Real lower bound (LB_r)	156.3	140.9	157.5
Theoretical upper bound (UB_t)	236.3	246.7	254.1
Real upper bound (UB_r)	237.5	245.6	256.0

Table 19. **System settlement delay (r) and liquidity usage (p) in the real lower and upper liquidity bounds, %, generated payment data, 100 days**

Hybrid scenario	Real lower bound		Real upper bound	
	Liquidity usage, π	Settlement delay, ρ	Liquidity usage, π	Settlement delay, ρ
Without TARGET transactions	18	6	27	0
TARGET: Short-term scenario	11	7	25	0
TARGET: Medium-term scenario	13	7	26	0

As can be seen from tables 18 and 19, the introduction of TARGET transactions had only a minor influence on the upper and lower bounds. Over the short term, the Hybrid structure with TARGET transactions produced slightly smaller theoretical and real lower bounds than without TARGET transactions. Over the medium term, the inclusion of TARGET transactions resulted in a slightly lower theoretical lower upper bound and slightly higher real lower bound.

The lower theoretical lower bound suggests that with the TARGET transactions the banks receive more payments in terms of value than they make and thus need less end-of-day net liquidity. The net effect of the former loro payments was zero, which means that the difference originates from the cross-border payments. Additionally TARGET payments can be assumed to be more time-critical and thus they result in a higher real lower bound. It should however be noted that the differences are small.

In respect of upper bounds, the inclusion of TARGET transactions results in slightly higher theoretical and real upper bounds, due to the time-criticalness of TARGET payments. The differences are however quite small in both cases. In relative terms, liquidity usage decreases slightly when the TARGET transactions are included. At the same time, the settlement delay increases but not significantly.

The source of the change in liquidity need can be divided into that due to the increased value of payments and that due to the structural changes in the settlement of payments. In order to isolate the first cause (increased payments value) we use the regression curve introduced in section 7.2 and estimate the expected liquidity usage with everything kept constant except the value of payments. Table 20 shows the expected and simulated values of π and absolute liquidity need per bank. The short-term TARGET scenario does not seem to have any structural effects; the entire increase in liquidity need can be explained by the increased value of payments settled. In the medium term the structural changes in the payment settlement seem to increase the liquidity need slightly, as the liquidity need indicated by the simulations is greater than what was expected because of the increased value of payments settled.

Table 20. **Estimated and simulated system p and upper bound of liquidity for both TARGET scenarios**

	Real upper bound	TARGET Short term	TARGET Medium term
Expected	π	24 %	24 %
	liquidity need*	350.4	352.8
Simulated	π	24 %	26 %
	liquidity need	352.3	373.2

* Average daily liquidity need of a bank, n=8.

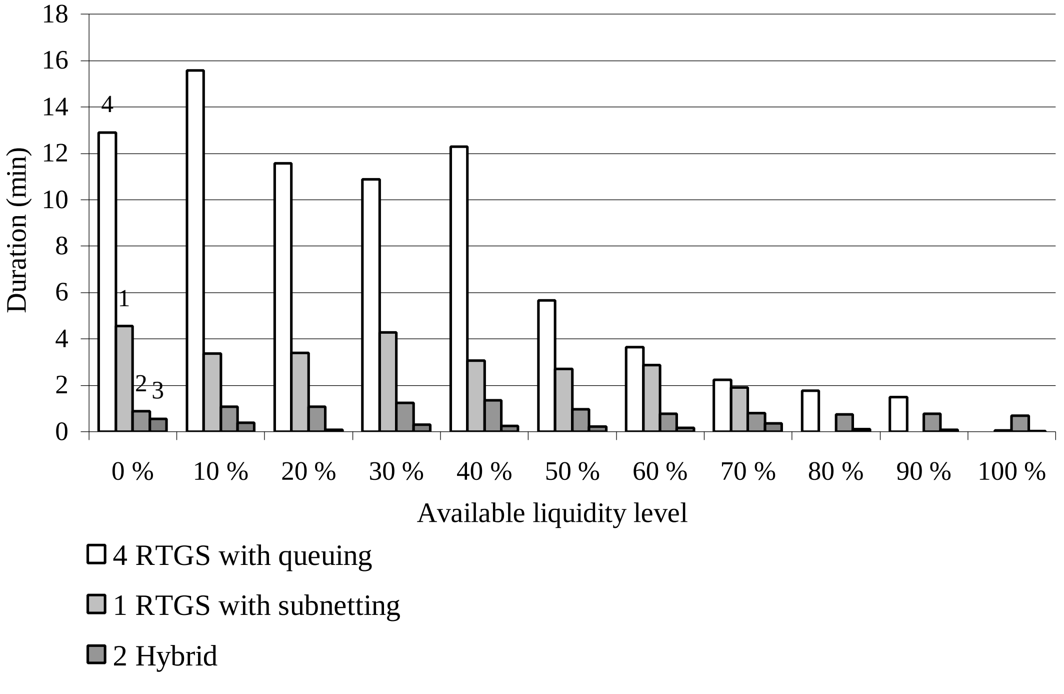
7.3.4 Occurrence of gridlocks in pre-selected scenarios

The probability of gridlock for all the pre-selected scenarios was found to be small using actual payment data. Only the Hybrid and RTGS-with-queuing structures experienced gridlocks during the four days with actual payment data. With the Hybrid structure, one gridlock (lasting eleven minutes) occurred on the second simulation day at an available liquidity level of zero (ie lower bound). With the RTGS-with-queuing structure, gridlocks occurred on three days with a daily average duration of 13 minutes at a liquidity level of zero and 40 minutes per day at a liquidity level of 10 per cent.

The reason why there were less gridlocks at the zero level of liquidity than at the 10 per cent level is that some gridlocks become illiquidity situations as system liquidity decreases. The system is actually halted longer at the zero level of liquidity, but there are relatively more illiquidity situations and less gridlocks than at the 10 per cent liquidity level.

With the Advanced Hybrid structure, the splitting of payments prevented the occurrence of gridlocks in simulations using the actual payment data.

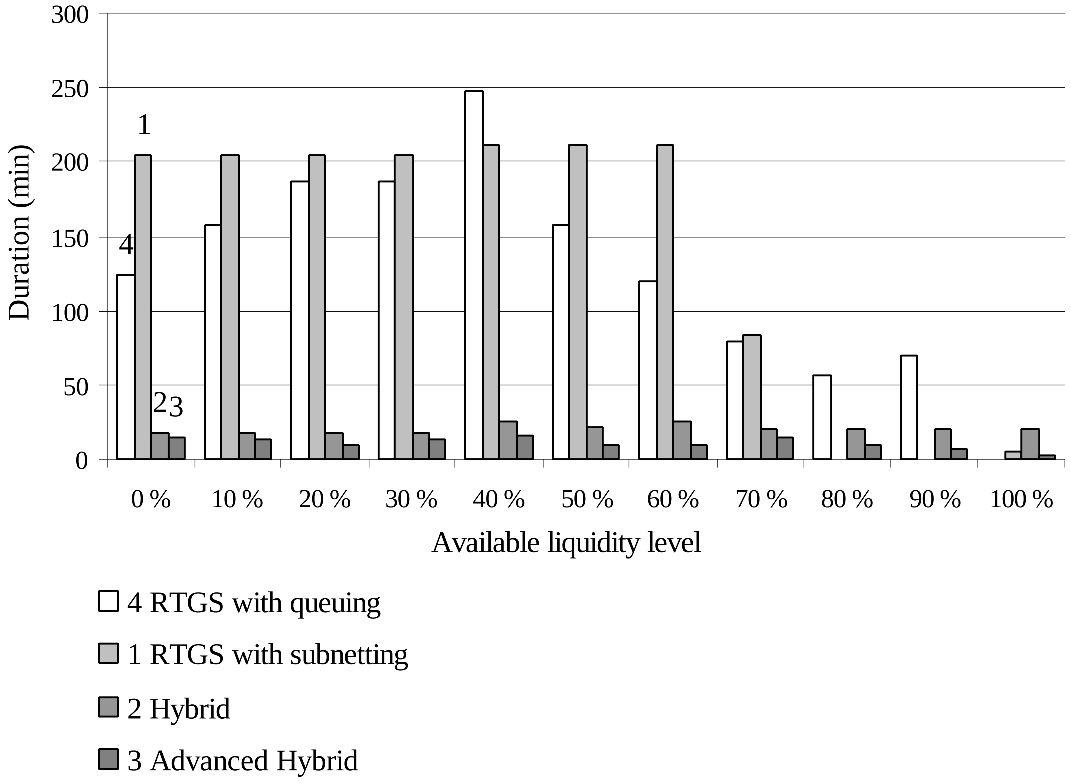
Figure 24. **Average daily gridlock duration for pre-selected payment system structures, generated data, 100 days**



With the 100 days of generated data, there were more gridlocks. With the RTGS-with-queuing structure with no optimization routines, the system was gridlocked for almost 16 minutes a day on average at the 10 per cent liquidity level. With the RTGS-with-subnetting structure, the system was gridlocked for four minutes a day on average at low liquidity levels and one to two minutes at high liquidity levels. With the Hybrid and Advanced Hybrid structures, gridlocks rarely occurred. These systems include optimization routines such as netting of queues (both structures) and splitting of payments (Advanced Hybrid structure), which helped to resolve most of the gridlock situations fairly quickly.

Figure 25 shows that, with the latter two structures, the peak daily gridlock duration was much smaller than with the former structures. The RTGS-with-subnetting structure resulted in gridlock for a total duration of 3.5 hours on the worst day and the RTGS-with-queuing structure more than four hours. With the Hybrid structure, the system was in gridlock for 25 minutes on the worst day and with the Advanced Hybrid structure only 16 minutes.

Figure 25. **Peak daily gridlock duration for pre-selected payment system structures, generated data, 100 days**



7.3.5 Main results

The liquidity needs of the Finnish banking sector seem to increase somewhat with the shift from the RTGS-with-subnetting structure to the Hybrid structure at the start of 1999. The simulations suggest that on average the existing intraday credit limits are sufficient, albeit some banks may need extra intraday credit or other extra liquidity. Although the liquidity need increases, the value of payments going through the system increases much more, ie the system works more efficiently. The result is that the Hybrid structure uses only slightly more than a third as much liquidity for a given amount of payment volume and settlement delay as the RTGS-with-subnetting structure and is thus much more efficient.

It is noteworthy that the curve representing the relationship between liquidity usage and settlement delay could include concave segments. A reduction in the level of available liquidity may result in greater usage of liquidity. Reducing the available liquidity may cause queuing at critical points of time during the day and so receivers of payments may have to raise their intraday credit limits in order to settle time-critical transfers on time. If the increase in limits is greater than the reduction in liquidity, the banks end up having greater liquidity needs.

Differences between the Hybrid and Advanced Hybrid structures were found to be very small. This suggests that making all POPS payments on a gross basis will not cause additional liquidity restraints, at least when payment splitting is used as a liquidity optimization method.

When TARGET transactions are introduced, liquidity needs increase slightly (as anticipated) as the value of payments increases. Liquidity usage decreases slightly and the change in settlement delay is insignificant. Thus one can say that, according to these simulations, inclusion of TARGET transactions with the Hybrid structure does not impose additional liquidity restraints on banks operating in the Finnish interbank payment system.

The real time gross settlement of all payments did not cause additional liquidity restraints or settlement delay. Only the occurrence of gridlocks was found to be greater for the RTGS-with-queuing structure than for the other systems. The probability of gridlock in the pre-selected scenarios was generally found to be fairly small. The introduction of optimization features like netting of queues (Hybrid and Advanced Hybrid structures) and splitting of payments (Advanced Hybrid structure) helped resolve gridlock situations.

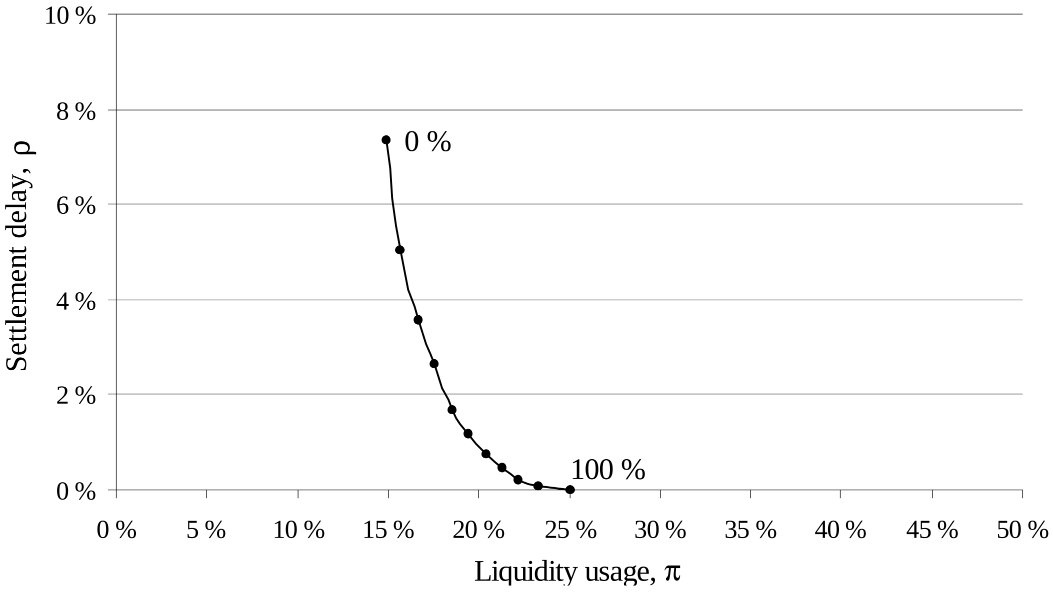
7.4 Simulations on the effects of optimization methods

The simulations on the effects of the optimization methods were done with the RTGS-with-queuing structure without time-critical payments or payment prioritization. The data used was the 100 days of generated payment data. The calculations take into account only banks participating in the payments system.

7.4.1 Queuing of payments

The liquidity need for making payments without settlement delay with the RTGS-with-queuing structure and generated payment data was about 25 per cent of the value of the payments (theoretical upper bound). The minimum liquidity need, ie the liquidity need of a system where all payments are settled on a net basis at the end of the day was about 15 per cent of the value of payments settled (theoretical lower bound). The speed of settlement, measured by ρ was almost seven times faster at the lower bound in the RTGS-with-queuing structure than in an end-of-day net settlement system.

Figure 26. **Relationship between settlement delay (r) and liquidity need (p) in RTGS-with-queuing structure, generated payment data, 100 days**



The relationship between liquidity usage and settlement delay in an RTGS-with-queuing structure without any optimization methods or prioritized payments is shown in figure 26. The curve is fairly steep, and the range over which liquidity can be substituted for settlement delay is about 10 per cent of the daily value of payments. The percentage change in settlement delay as the level of liquidity decreases remains fairly stable after the liquidity level of 70 per cent, at a 50 per cent increase per level. This can be seen in the figure as the constantly increasing vertical distances between subsequent liquidity levels marked as dots on the curve. As the curve in the figure is concave and steep, the increase in the delay of settlement increases at a faster rate at low levels than at high levels of liquidity.

In an RTGS system without queuing, system liquidity usage is on average twice the sum of account holders' daily net positions. The daily difference with queuing ranged from just 14 per cent greater liquidity usage to 434 per cent greater usage for the 100-day period. On the best day, all payments could be settled with system liquidity amounting to only 3.7 per cent of the gross value of payments at the zero liquidity level. This implies a turnover ratio of 27. The average turnover ratio was about four. On the worst day, π equalled 35.9 per cent at the 100 per cent liquidity level (see table 21).

Table 21. **System liquidity need (p) and settlement delay (r) in the RTGS-with-queuing structure, selected liquidity levels, generated payment data, 100 days**

Liquidity level, %	Average, π, %	Maximum, π, %	Minimum, π, %	Average, ρ, %	Maximum, ρ, %	Minimum, ρ, %
0	14.2	28.7	3.7	7.3	41.7	0.4
10	15.3	29.1	5.1	5.0	25.3	0.3
20	16.4	29.5	6.5	3.6	23.1	0.2
30	17.5	29.9	7.9	2.6	17.0	0.1
40	18.5	30.3	9.3	1.7	10.2	0.1
50	19.6	30.8	10.7	1.2	8.7	0.1
60	20.7	31.5	12.1	0.7	3.5	0.1
70	21.8	32.1	13.5	0.5	2.5	0.0
80	22.9	33.4	14.9	0.2	1.1	0.0
90	24.0	34.6	16.3	0.1	0.6	0.0
100	25.1	35.9	17.2	0.0	0.0	0.0

7.4.2 Splitting of payments

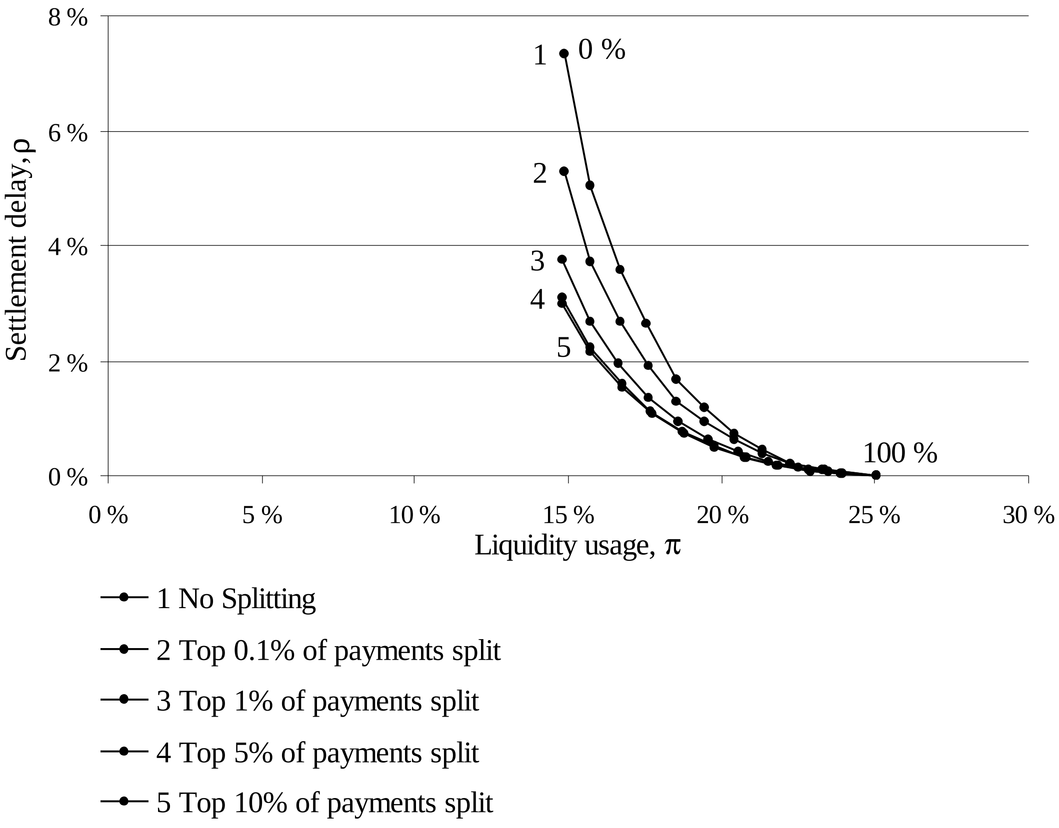
The splitting levels and the equivalent minimum values for payments to be split are shown in table 22. In the type of splitting used in this study, the original payment is split into equal-size payments so that the value of a payment is less than or equal to the split limit (see section 4.1.3).

Table 22. **Simulations on the splitting of payments**

Upper percentile split, %	Minimum value for payment split, mill. ECU
10	1.9
5	7.1
1	54.7
0.1	227.9

The relationship between liquidity usage and settlement delay for each of the split limits is shown in figure 27. In general, settlement delay can be reduced at all levels of liquidity by splitting large payments into several smaller ones. The effects of payment splitting were however greater at low levels of liquidity.

Figure 27. **Effects of payment splitting on system liquidity usage (p) and settlement delay (r)**



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.

Table 23. **Relative changes in settlement delay (ρ) with selected split limits**

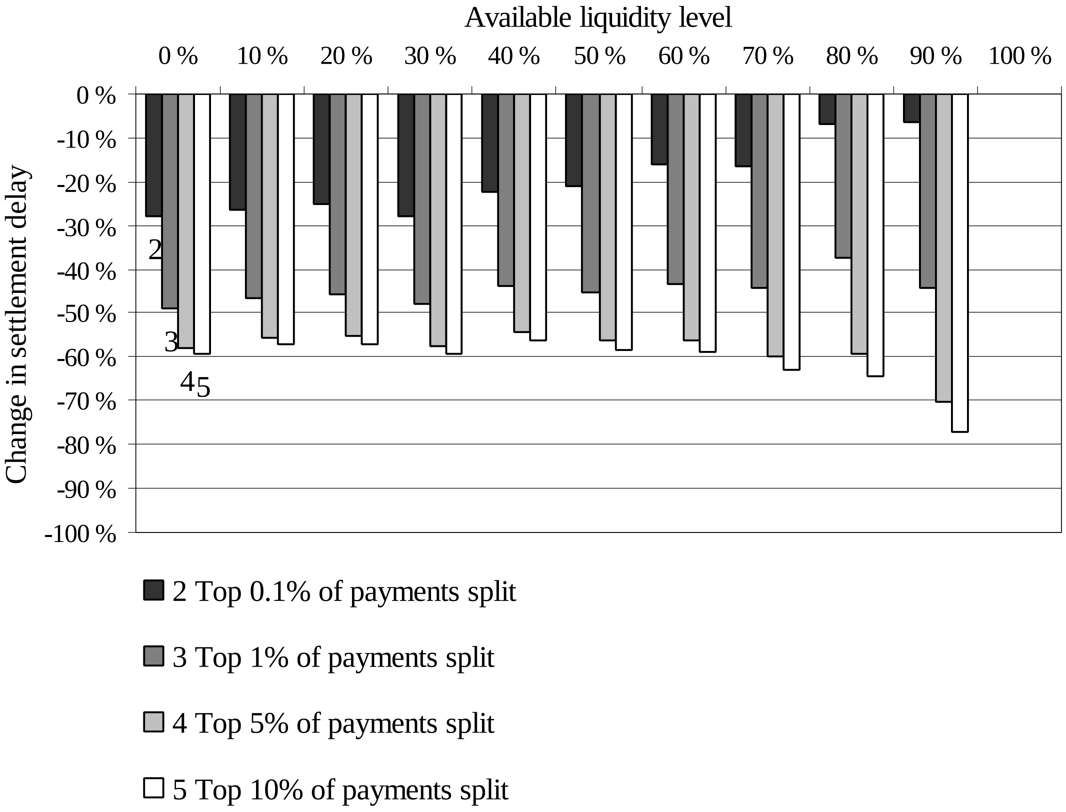
Shift between systems	Change in settlement delay[1], %
no splitting (1) -> split 0.1% (2)	-19.6
split 0.1% (2) -> split 1.0% (3)	-30.9
split 1.0% (3) -> split 5.0% (4)	-24.2
split 5.0% (4) -> split 10.0% (5)	-7.4

[1] 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 7.4 per cent on average. Splitting the top 5 per cent reduced settlement delay by 24.2 per cent, compared to splitting the top 1 per cent, and the shift from 0.1 per cent to 1 percent reduced settlement delay by 30.9 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 delay.

The change in queuing resulting from the splitting of payments is summed up in figure 28. 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.

Figure 28. **Change in system settlement delay (r) resulting from payment splitting at selected levels of liquidity**



The effect of payment splitting on settlement delay seems to vary between the groupings of payments that are split. The effect of splitting the top 0.1 per cent payment group diminishes as system liquidity increases. For splitting of the top 1 per cent of payments, the effect is roughly the same at each liquidity level. This suggests that the splitting of only the largest payments helps relatively more when liquidity is scarce. If settlement delay is to be reduced in looser liquidity situations, the split limit must be considerably lower.

The effect of splitting the top 5 per cent or 10 per cent of payments remains relatively stable up to liquidity levels of 70–80 per cent, after which the effect increases as system liquidity increases.

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. Payment splitting can help only in preventing gridlocks; it has no effect on illiquidity situations.

On the other hand, settlement delay is calculated in this study as the ratio of the cumulated value of queued payments through the day relative to the cumulated value of payments at each minute and hence payment splitting affects the numerator. As payments are split, less of the value of the original payment is left in queue and so account holders' liquidity is used more efficiently. The smaller the value of the payment that is split, the greater the effect on settlement delay as calculated in this study. Thus the reduction in settlement delay is due partly to the prevention of gridlocks during the day and partly to a reduction in the value of queued payments.

Most of the gridlocks occurred in the simulations at the zero liquidity level, with an average gridlock duration of 14 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 20 per cent, the average daily total duration of gridlocks was short.

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, ie at the zero level of liquidity. The splitting of the top 5 per cent of payments was also very 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 29. **Effect of payment splitting on average daily gridlock duration as a function of liquidity**

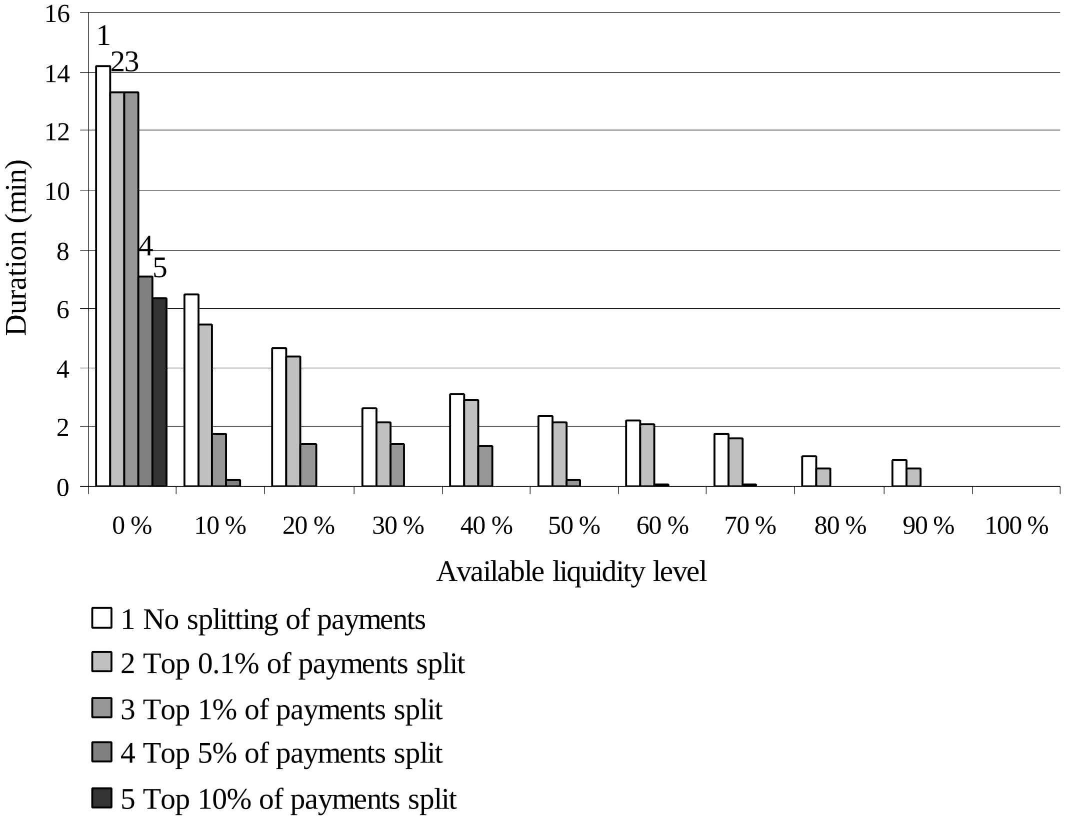
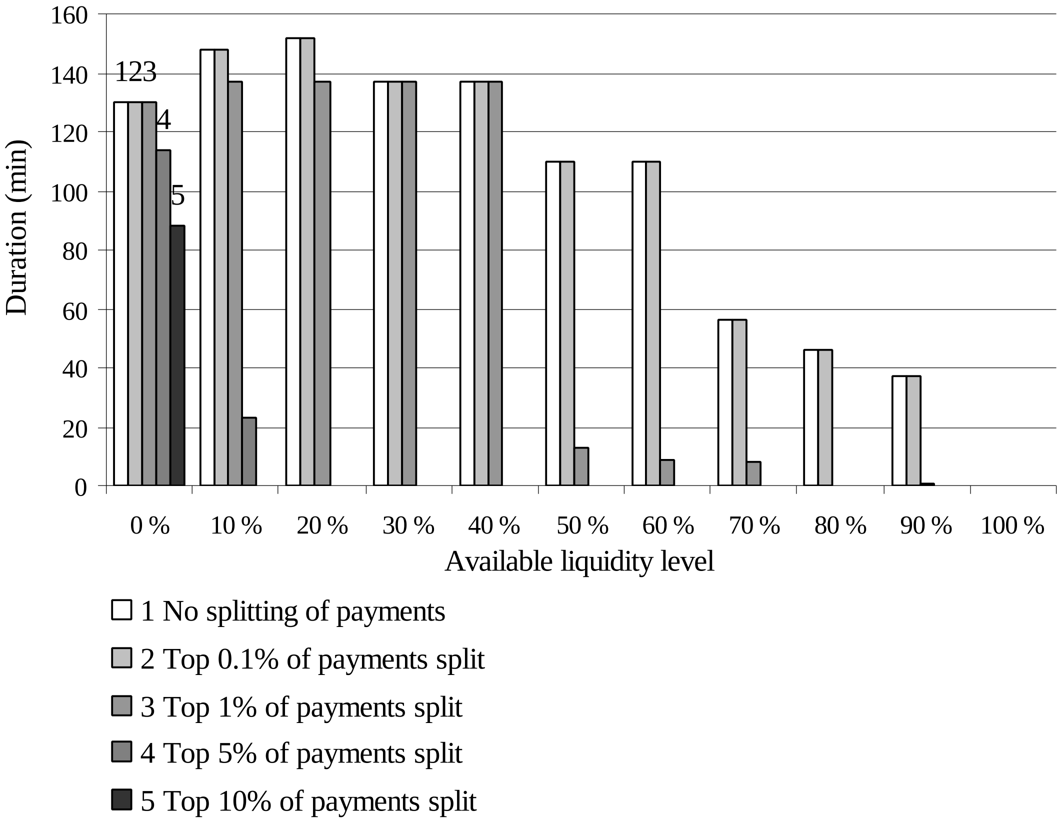


Figure 30 illustrates the worst gridlock days. As one can see from the figure, there is a significant difference in the effects of splitting depending on whether the top 1 per cent or 5 per cent of payments are split. In the latter case, the peak duration of daily gridlocks was significantly shorter. 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. This means that, without optimization routines, liquidity equal to the liquidity used by a net settlement system with end-of-day net settlement (ie theoretical lower bound) was not sufficient. In the simulations these gridlocks were solved by executing a net settlement on the remaining queued payments. This provides further evidence of the need for optimization routines in RTGS systems.

Figure 30. **Effect of payment splitting on peak daily gridlock duration as a function of liquidity**

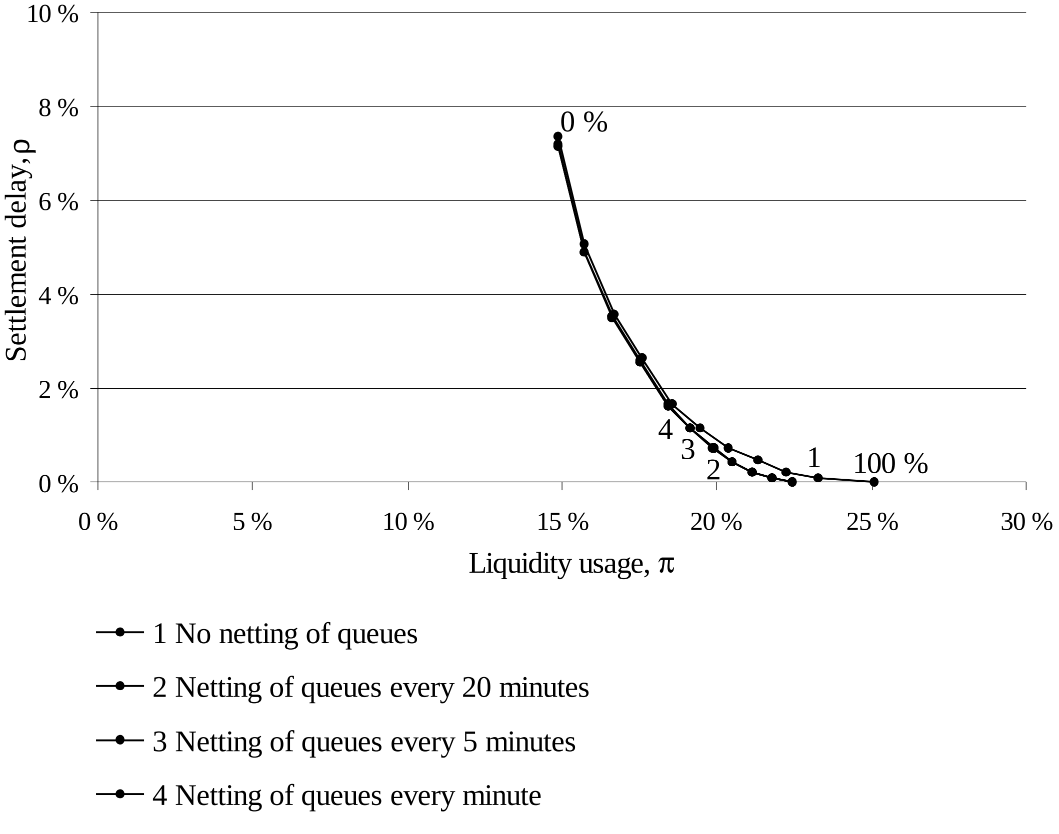


7.4.3 Netting of queues

The netting of queues 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.

As can be seen from figure 31, the netting of queues is effective in reducing settlement delay only for the higher liquidity levels and even then only with minor effect. Curves 2, 3 and 4 in the figure representing systems with different netting intervals appear to coincide, but there are small differences, as becomes clear in figure 32.

Figure 31. **Effect of netting of queues on system liquidity usage (p) and settlement delay (r) at selected netting intervals**



The netting of queues has the greatest impact on queuing at the 90 per cent liquidity level. This is quite natural because at this level participants have the most liquidity and so the netting of queues is the most likely to succeed. Accordingly, the effect of queues netting is minimal at the lowest level of liquidity because the amount of available funds is not sufficient to settle the net amounts of queued payments.

The effectiveness differences between the three time intervals for netting of queues are visible only at the upper levels of liquidity. These differences are clear but small, the shorter intervals being more effective.

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. 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 the one- and five-minute time-intervals much more effective than the 20-minute interval.

Figure 32. **Change in system settlement delay (r) due to use of netting of queues at selected time intervals**

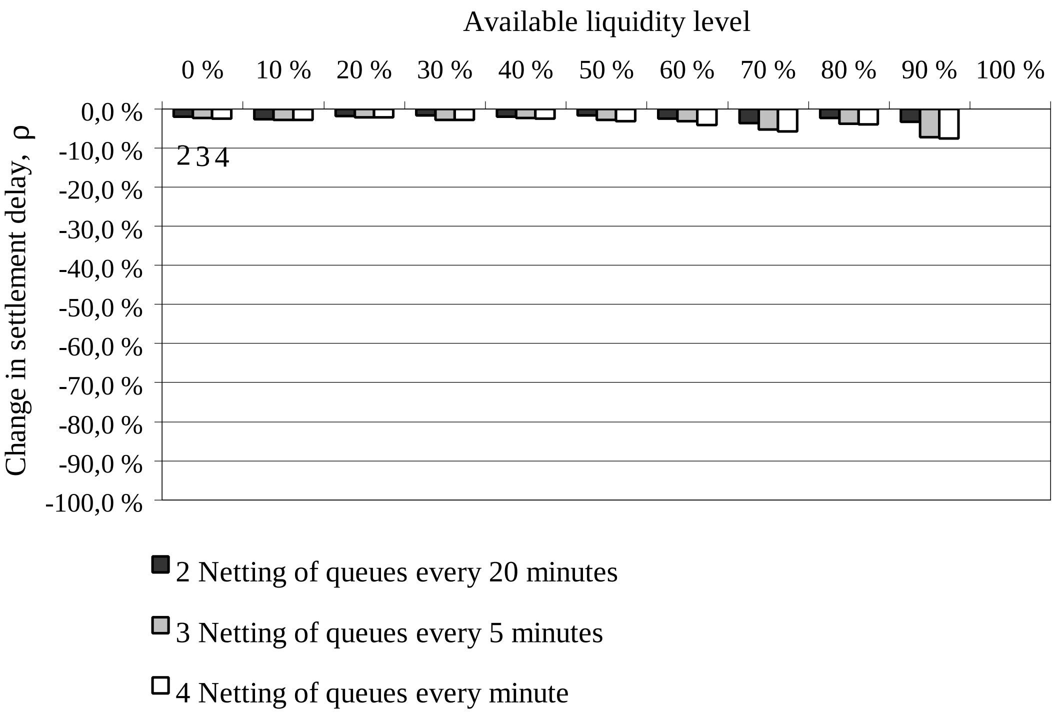
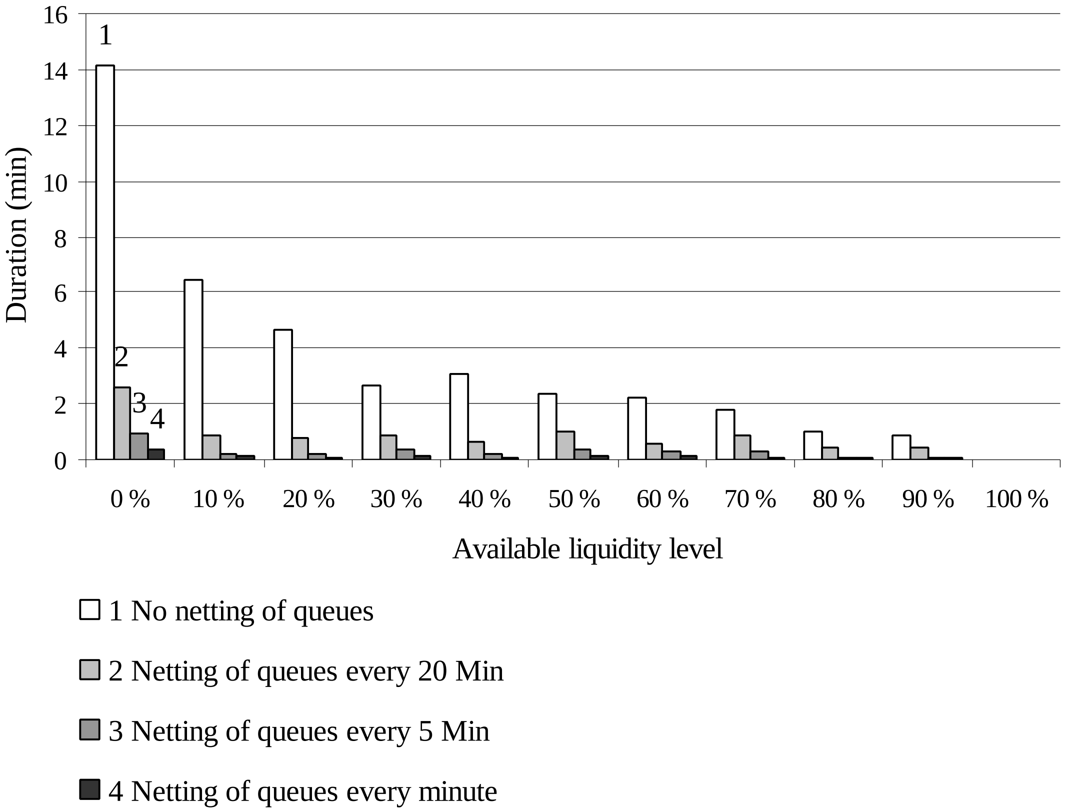


Figure 33 clearly shows that the netting of queues is a very effective method of reducing the time that the system is gridlocked (gridlock duration). It should however be noted that there were very few gridlocks on average. With a 20-minute netting interval, gridlock duration was on average only a fourth as long as for a system without this feature. With a 5-minute time interval, 1/13 as many minutes of gridlock occurred during the 100-day period.

Figure 33. **Effect of netting of queues on average daily gridlock duration as a function of liquidity**



On the worst day (see figure 34) the peak daily gridlock duration was over 2 and a half hours for a system with no optimization routines.[21] In this case the effect of the netting of queues is significant and quite similar regardless of liquidity level. When the netting of queued transfers was executed every minute, worst-day gridlock duration was only three minutes. 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.

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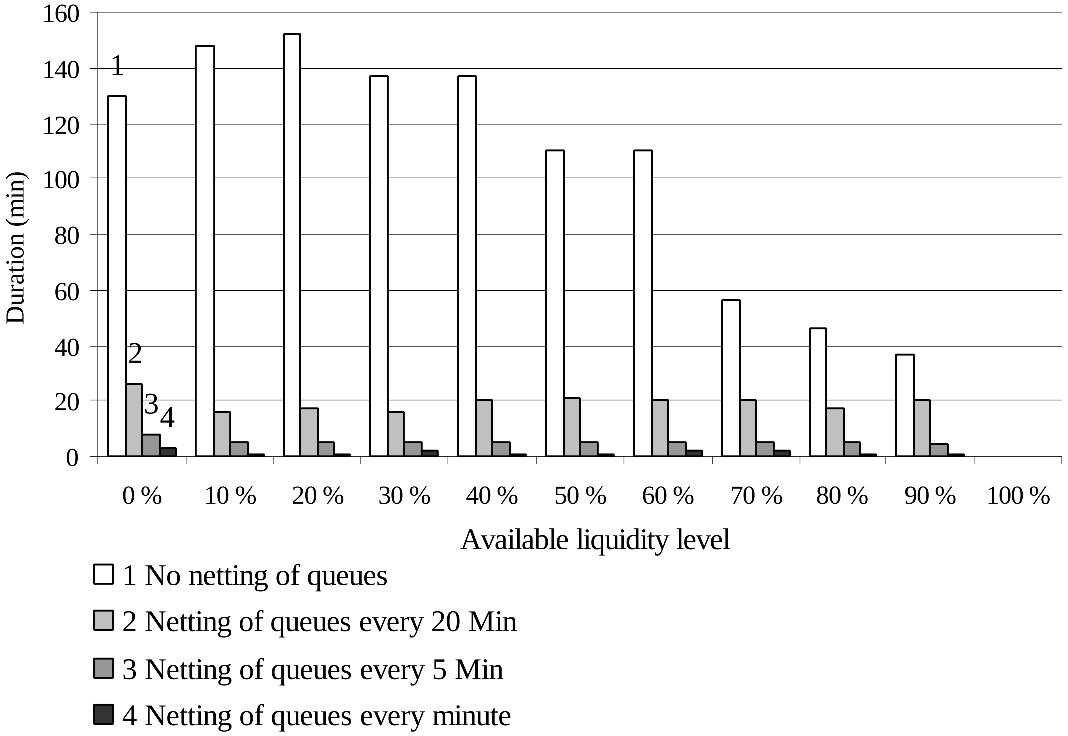
[21] Gridlock duration is the total minutes that the system is gridlocked. Thus daily gridlock duration can exceed 20 minutes, which is the longest time interval between attempts to net the queues.

Figure 34. **Effect of netting of queues on peak daily gridlock duration as a function of liquidity**



7.4.4 Main results

According to the simulations, the splitting of payments is a more effective method of reducing settlement delay than the netting of queues. The reason is that payment splitting works bilaterally between participants and thus does not require that all banks be liquid, as does the netting of queues studied here. Payment splitting also makes more efficient use of available liquidity since the maximum momentary residual liquidity (unused liquidity) for a bank with queued payments is equal to the limit to which the payments are split.

It should however be noted that only multilateral netting of queues was studied, this being the most common way of netting queues. In principle, queues could also be netted bilaterally, which might be more effective than the multilateral approach used here.

For resolving gridlock situations, the netting of queues seemed to be more effective than payment splitting at low levels of liquidity. The splitting of payments with a sufficiently low split limit (top 1 per cent of payments split) seemed to prevent the formation of gridlocks in the first place at higher levels of liquidity. It should however be noted that the splitting of payments did not completely prevent the formation of gridlocks, whereas the netting of queues, by our definition, solves a gridlock immediately when it is executed. Some gridlocks occurred 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.

8 Conclusions

8.1 The adequacy of liquidity in the Finnish banking sector

The adequacy of liquidity for payment settlement in the Finnish banking sector was studied with the payments systems simulator and by using actual payment data and actual intraday credit limits.

The liquidity need of the Finnish banking sector seems to increase with a changeover from the RTGS-with-subnetting payment system structure to the Hybrid structure. Although the total value of payments flowing through the RTGS system was higher on average in the Hybrid structure, the current intraday credit limits of the banks were sufficient. However, some banks experienced delays in settlement, and any additional liquidity would reduce such delays. The upside of the shift from net to gross settlement is of course the greatly reduced overall settlement delay and settlement risks.

No highly significant differences were found between the Hybrid, Advanced Hybrid, and RTGS-with-queuing structures. However, total time of system gridlock was greater (albeit still quite small) for the RTGS-with-queuing structure than for the other systems. The RTGS-with-queuing structure did not include any optimization features, and the inclusion of such features in the Hybrid and Advanced Hybrid structures helped resolve most of the gridlock situations fairly quickly.

The introduction of TARGET transactions had only a minor influence on banks' liquidity needs and settlement delay. Thus it can be said that according to these simulations the inclusion of TARGET transactions in the Hybrid model does not impose additional liquidity restraints on banks operating in the Finnish interbank payment system, although the absolute values of liquidity needs are somewhat higher. It should be noted that time stamps for the TARGET transactions were randomly chosen and the distributions over the day of incoming and outgoing transfers were assumed to be the same. If eg most of the transfers are outgoing at the start of the day and incoming at the end of the day, the additional liquidity need during the day might be substantial.

8.2 The efficiency of different settlement structures

The efficiency of the pre-selected settlement scenarios was studied in terms of the relationship between liquidity usage and settlement delay at specified liquidity levels.

Liquidity needs increase considerably for all payment system structures studied if the banks settle their payments immediately without queuing instead of settling net positions at the end of the day. It should however be recalled that an RTGS system is capable of operating at the same liquidity level as a net settlement system. In an RTGS system, settlement delay is explicit in the queuing of payments, and in a TDNS with the same risk characteristics, fund transfers become final when the net positions are settled between the settling banks. In the simulations, the RTGS-with-queuing structure was about three and a half times faster in settling payments than an end-of-day net settlement system with the same amount of liquidity.

Focusing solely on liquidity usage, the RTGS-with-queuing structure seems to be the superior system structure for the banks. However, at the lower levels of liquidity, this structure results in extensive, perhaps intolerable, settlement delays. This suggests that the RTGS-with-queuing structure may be the best choice only if the banks operate at high liquidity levels. Thus both the Hybrid and Advanced Hybrid structures can be seen as good compromises between liquidity usage and settlement delay at all liquidity levels. The results using both generated and actual payment data pointed in the same direction.

Another interesting result was the concavity of the relationship between settlement delay and liquidity need at some points in the curve representing the tradeoff between liquidity usage and settlement delay. In some situations, low liquidity positions for the banks at the start of the day led to queuing at times when time-critical payments were due. As the liquidity for settling these transfers is tied up in queues, the receivers of these transfers could be forced to raise their credit limits or otherwise acquire liquidity. The liquidity that has to be acquired by the receiver of a queued payment might be larger than the liquidity that has to be acquired by the sender of the payment in order to enable the receiver settle its own queued payment.

8.3 The effects of optimization methods

The effects of optimization methods were examined for an RTGS settlement structure without payment prioritization or time-critical payments. Simulations were done using the 100 days of generated payment data. The tested methods were the splitting of payments and the netting of queued payments.

Both optimization methods clearly improved the working of the system and the settlement of payments. The splitting of payments seemed to be more effective in reducing settlement delay than the complete netting of queues. The splitting of payments works bilaterally between participants and increases the circulation of liquidity in the system. The existing liquidity is better utilized by splitting the payments and thus settlement delay is substantially reduced. The complete netting of queues did reduce settlement delay but only slightly, by solving gridlocks.

The netting of queued transfers seemed to be more effective in resolving gridlock situations at low levels of liquidity. Splitting of payments was however more effective at high levels of liquidity, as it prevented the formation of gridlocks. At the lowest levels of liquidity, the split limits applied here were not small enough to prevent all gridlocks.

8.4 Suggestions for future research

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, 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 routines for bilateral netting of queues. 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.

The results concerning the adequacy of liquidity and the bounds for liquidity in the EMU structure with TARGET transactions can be refined as actual data on TARGET transactions becomes available. After some time, as historical data in the context of the EMU becomes available, one will be able to more accurately measure the effects of optimization routines using a longer period of actual payment data.

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Appendix 1. Key values from simulations of pre-selected systems

Table 1. **Standard deviation of balances (mill. ECU), actual payment data, 4 days**

Day	RTGS with subnetting	Hybrid	Advanced Hybrid	RTGS with queuing
12.5.	58	83	83	66
13.5.	107	150	150	151
14.5.	88	111	111	108
15.5.	51	56	56	53

Table 2. **Average usage of intrady credit limits (%), actual payment data, 4 days**

Day	RTGS with subnetting	Hybrid	Advanced Hybrid	RTGS with queuing
13.5.	4.6	12.4	12.3	9.2
14.5.	7.2	17.3	18.4	18.7
15.5.	8.6	15.6	15.7	15.1
16.5.	6.2	7.7	7.4	7.7

Table 3. **Average and peak queuing times for queued payments, actual payment data, 4 days**

	Average queuing time for queued payments, h:mm				Peak queuing time for queued payments, h:mm			
Day	RTGS with Sub-netting	Hybrid	Advanced Hybrid	RTGS with queuing	RTGS with Sub-netting	Hybrid	Advanced Hybrid	RTGS with queuing
13.5.	0:00	0:32	0:38	1:25	0:00	1:00	1:00	1:55
14.5.	0:16	0:44	0:21	0:21	0:30	3:01	3:01	2:28
15.5.	0:00	0:48	0:44	0:44	0:00	1:31	1:31	1:31
16.5.	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00

Table 4. Number and average value (mill. ECU) of queued payments, actual payment data, 4 days

	Number of queued payments				Average value of queued payments			
Day	RTGS with Sub-netting	Hybrid	Advanced Hybrid	RTGS with queuing	RTGS with Sub-netting	Hybrid	Advanced Hybrid	RTGS with queuing
13.5.	0	2	5	9	0	42.4	3.7	0.2
14.5.	2	27	192	58	114.0	19.1	3.1	15.1
15.5.	0	12	16	16	0	2.7	2.1	2.1
16.5.	0	0	0	0	0	0	0	0

Table 5. Queues (mill. ECU), actual payment data, 4 days

	RTGS with Subnetting	Hybrid	Advanced Hybrid	RTGS with queuing
Peak Value	227.9	204.5	208.0	459.5
Average Value	114.0	43.8	25.1	110.3
Peak Volume	1.0	15.0	64.0	31.0
Average Volume	1.0	2.2	4.5	3.8

Appendix 2. 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.

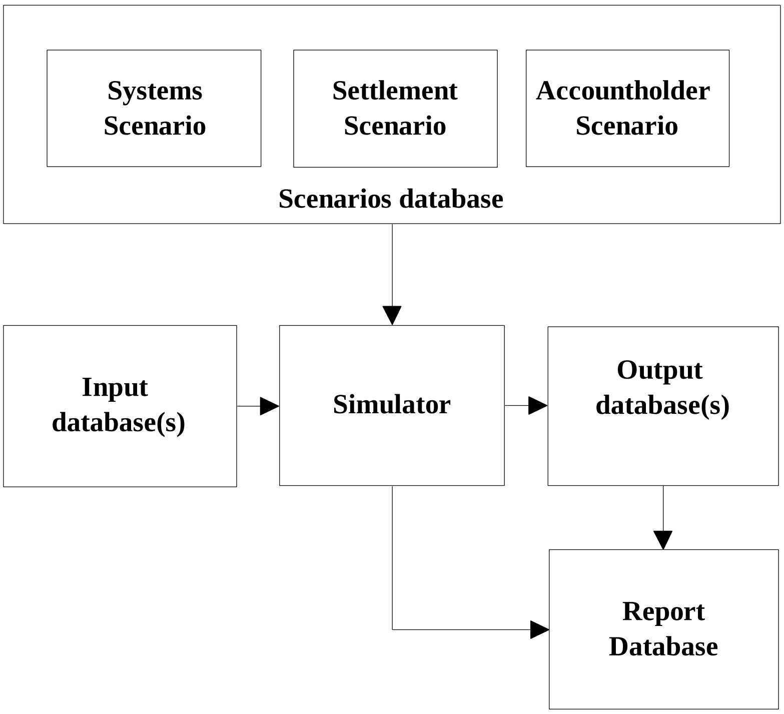
For time designated net settlement systems, the net positions for each account holder are also updated.

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 1.

The variables reported by the simulator are summarized in table 1. The scope of the variable reported is denoted in table 1 as follows:

a) for each account holder if the variable is reported for each individual account holder,
t) 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 1. **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 1. **Variables reported by the simulator**

Variable	Scope	Description	Systems
After each transaction			
Time stamp	a	Time of transaction	r,c
Balance	a	Balance of settlement account	r,c
Liquidity	a	(Starting balance + limit) – Balance	r,c
Queue value (sum)	a	Total value of queued payments	r,c
Payments queued	a	Number of queued payments	r,c
Payments sent (cumulative)	a	Cumulative sum of payments sent	r,c
RTGS/CNS limits	a	Current RTGS or CNS limits	r,c
For each payment settled			
Identification number	t	Ordinal number of entry into system	r,c,t
Settlement number	t	Ordinal number of settlement	r,c,t
Entry time	t	Time when payment was entered into system	r,c,t
Value	t	Value of the payment, mill.	r,c,t
Receiver ID	t	ID of receiving account holder	r,c,t
Sender ID	t	ID of sending account holder	r,c,t
Priority	t	Priority of payment	r,c,t
Settlement time	t	Time when payment was settled	r,c,t
Settlement type ID	t	ID of the settlement system used for settlement	r,c,t
Time queuing	t	Queuing time for a payment: ie settlement time minus entry time	r,c
For each minute during the day			
Balance (low)	a	Lowest value of balance	r,c
Limit usage (peak)	a	Percentage of limits used, ie -[Balance]/[Limit] if [Balance]<0 and 0 if [Balance]>0	r
Value of queued payments	a	Value of queued payments at end of each minute	r,c
Queued payments	a	Number of queued payments at the end of each minute	r,c
Value of queued payments	a	Total value of queued payments at each minute	r
Queued payments	a	Number of queued payments at each minute	r
Cumulated value of queued payments	a	Value of queued payments cumulated over time	r
Cumulated queued payments	a	Queued payments cumulated over time	r
For each run			
Value of queue (avg, peak)	a	Average/peak value of queue at each minute	r
Queued payments (avg, peak)	a	Average/peak number of queued payments at each minute	r
Individual queuing time (avg, peak)	a	Average/peak time period during which individual payments are queued	r
Value of individual queued payments (avg, peak)	a	Average/peak value of individual queued payments	r
Balance (avg, peak, low, st dev)	a	Average/peak/low/standard deviation of intra-minute minimum balances	r

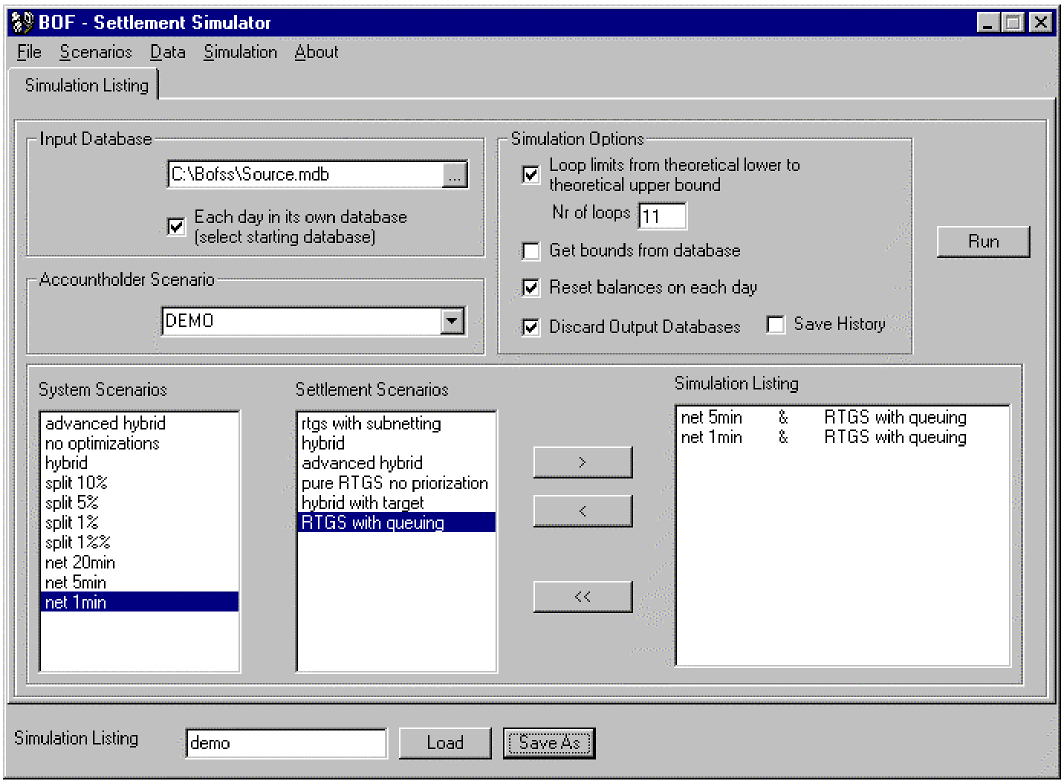
Variable	Scope	Description	Systems
Liquidity (low)	a	The lowest liquidity position during the day	r
Credit limit (low, peak)	a	The maximum value of intraday credit limit	r
Value of sent payments	a	Total value of payments sent	r,c,t
Payments sent	a	Number of payments sent	r,c,t
Queue %	a	Calculated as value of queue (peak)/value of sent payments	r
π	a	Represents degree of liquidity usage	r
ρ	a	Represents degree of settlement delay	r
Number of CNS transfers	a	Total number of CNS transfers during the day	c
Value of CNS transfers (tot, avg)	a	Total/average value of CNS transfers during the day	c
Queuing time (avg, peak)	a	Average/peak time period during which payments are queued	r,c
Daily number of queued payments	a	Total number of payments queued during the day	r,c
Gridlock duration	d	Total number of minutes system was gridlocked during the day	r
End-of-day gridlock	d	A Boolean variable indicating weather system was gridlocked at end of day	r
Balance (start, end)	a	Day’s starting/ending balance	r
Run ID	d	Identification number of the simulation run	
Data ID	d	Payment data used in current run	
Limit used	d	Size of limits used in current simulation run	
Settlement scenario ID	d	ID of settlement scenario used	
System scenario ID	d	ID of system scenario used	
Account holder scenario ID	d	ID of account holder scenario used	
Liquidity usage	d	Liquidity used by the whole system	
System value of sent payments	d	Total value of payments sent by the whole system	
For each payment datum used			
Daily value of sent payments (avg, peak, low, st dev, tot)	a	Average/peak/low/standard deviation/total value of payments sent during the day	
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	r
Theoretical lower liquidity bound (avg)	a	Average of theoretical lower bounds for day’s liquidity need	r
For each series of runs			
Number of daily sent payments (avg, tot)	a	Average/total number of payments sent during the simulation period	
Std deviations of daily value of sent payments (avg)	a	Average standard deviation of daily values of payments sent during the simulation period	
Total value of sent payments (avg, peak, low, tot)	a	Average/peak/low/total value of payments sent during the simulation period	

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

3 Simulator screenshots

Figure 1. **View of simulation settings**



Input Database: C:\Bofss\Source.mdb

☑ Each day in its own database (select starting database)

Accountholder Scenario: DEMO

Simulation Options

☑ Loop limits from theoretical lower to theoretical upper bound

Nr of loops: 11

☐ Get bounds from database

☑ Reset balances on each day

☑ Discard Output Databases ☐ Save History

System Scenarios:

- advanced hybrid
- no optimizations
- hybrid
- split 10%
- split 5%
- split 1%
- split 1%%
- net 20min
- net 5min
- net 1min

Settlement Scenarios:

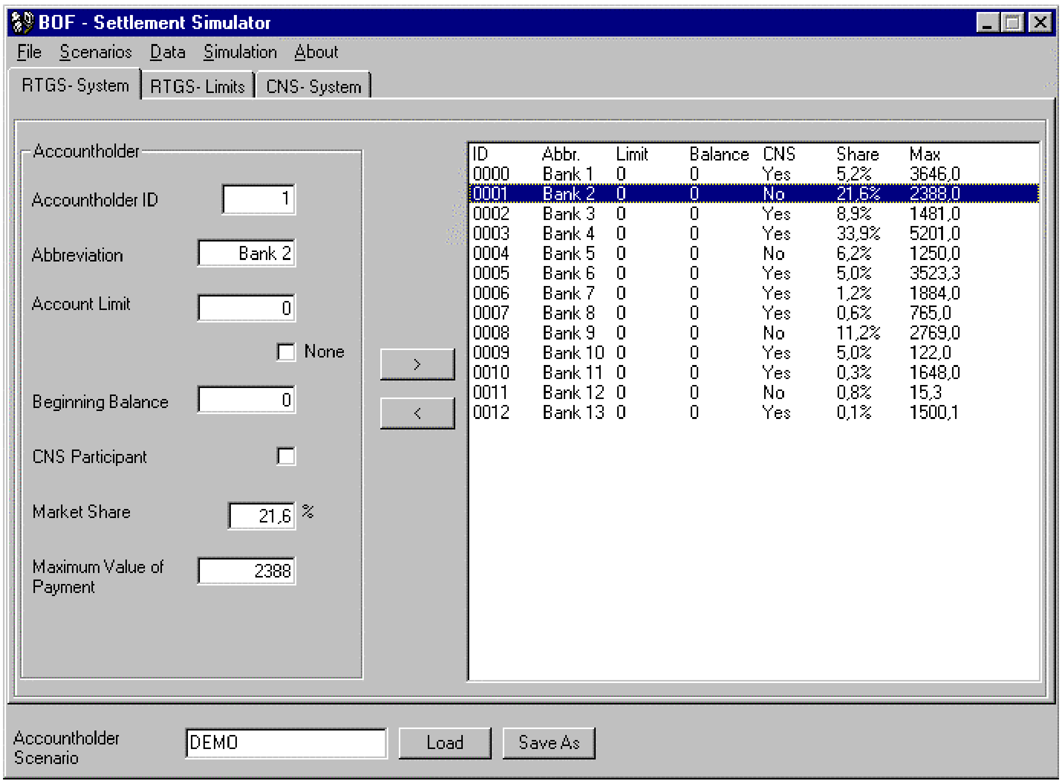
- rtgs with subnetting
- hybrid
- advanced hybrid
- pure RTGS no priorization
- hybrid with target
- RTGS with queuing

Simulation Listing:

net 5min & RTGS with queuing
net 1min & RTGS with queuing

Simulation Listing: demo

Figure 2. **View of account holder scenario: RTGS system participants**



Accountholder

Accountholder ID: 1

Abbreviation: Bank 2

Account Limit: 0

☐ None

Beginning Balance: 0

CNS Participant ☐

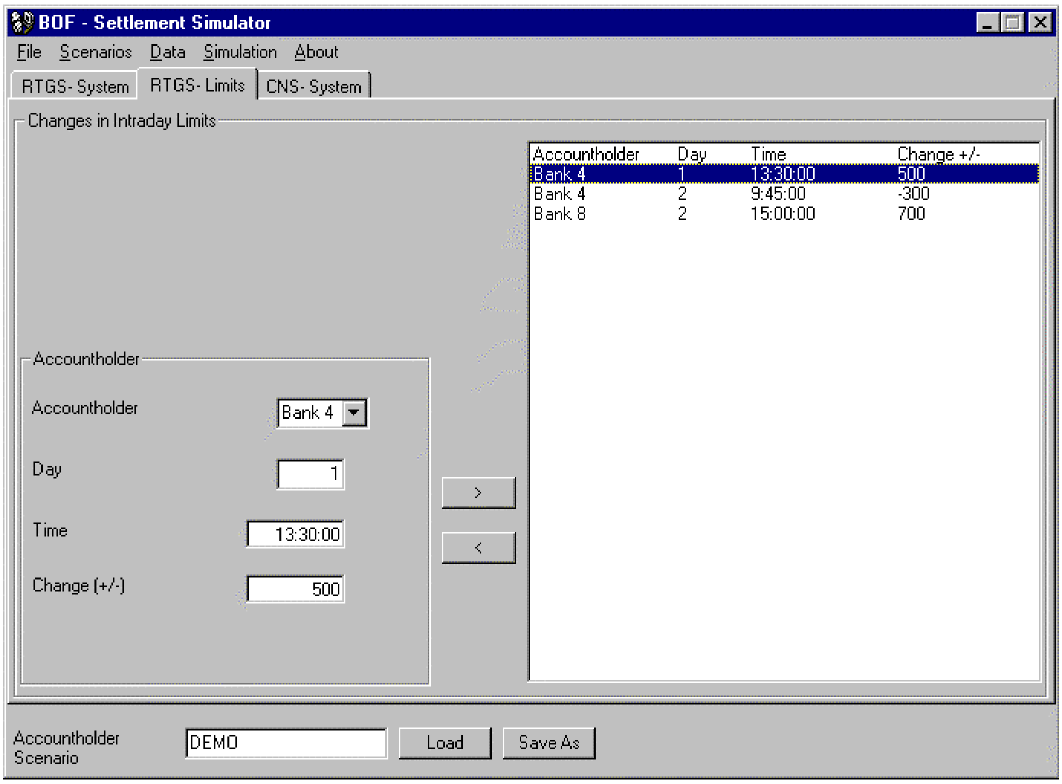
Market Share: 21,6 %

Maximum Value of Payment: 2388

ID	Abbr.	Limit	Balance	CNS	Share	Max
0000	Bank 1	0	0	Yes	5,2%	3646,0
0001	Bank 2	0	0	No	21,6%	2388,0
0002	Bank 3	0	0	Yes	8,9%	1481,0
0003	Bank 4	0	0	Yes	33,9%	5201,0
0004	Bank 5	0	0	No	6,2%	1250,0
0005	Bank 6	0	0	Yes	5,0%	3523,3
0006	Bank 7	0	0	Yes	1,2%	1884,0
0007	Bank 8	0	0	Yes	0,6%	765,0
0008	Bank 9	0	0	No	11,2%	2769,0
0009	Bank 10	0	0	Yes	5,0%	122,0
0010	Bank 11	0	0	Yes	0,3%	1648,0
0011	Bank 12	0	0	No	0,8%	15,3
0012	Bank 13	0	0	Yes	0,1%	1500,1

Accountholder Scenario: DEMO

Figure 3. **View of the account holder scenario: pre-programmed changes in intraday credit limits**



Changes in Intraday Limits

Accountholder	Day	Time	Change +/-
Bank 4	1	13:30:00	500
Bank 4	2	9:45:00	-300
Bank 8	2	15:00:00	700

Accountholder

Accountholder: Bank 4

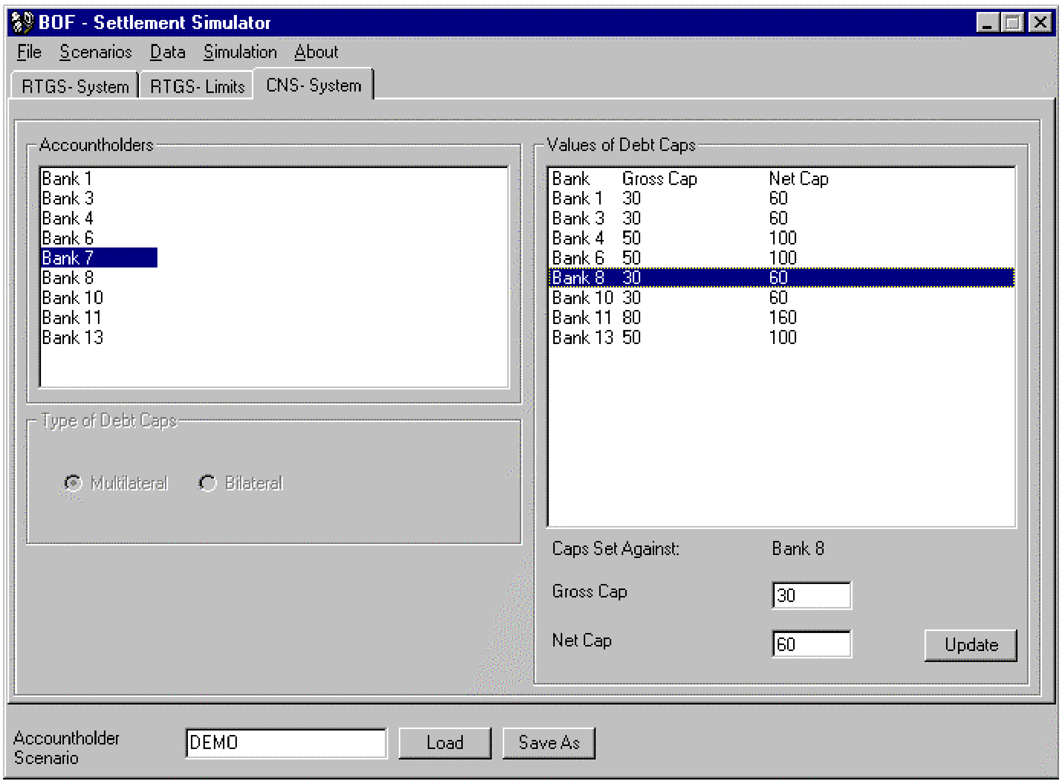
Day: 1

Time: 13:30:00

Change (+/-): 500

Accountholder Scenario: DEMO

Figure 4. **View of account holder scenario: CNS credit limits**



Accountholders

- Bank 1
- Bank 3
- Bank 4
- Bank 6
- Bank 7
- Bank 8
- Bank 10
- Bank 11
- Bank 13

Type of Debt Caps

● Multilateral ○ Bilateral

Values of Debt Caps

Bank	Gross Cap	Net Cap
Bank 1	30	60
Bank 3	30	60
Bank 4	50	100
Bank 6	50	100
Bank 8	30	60
Bank 10	30	60
Bank 11	80	160
Bank 13	50	100

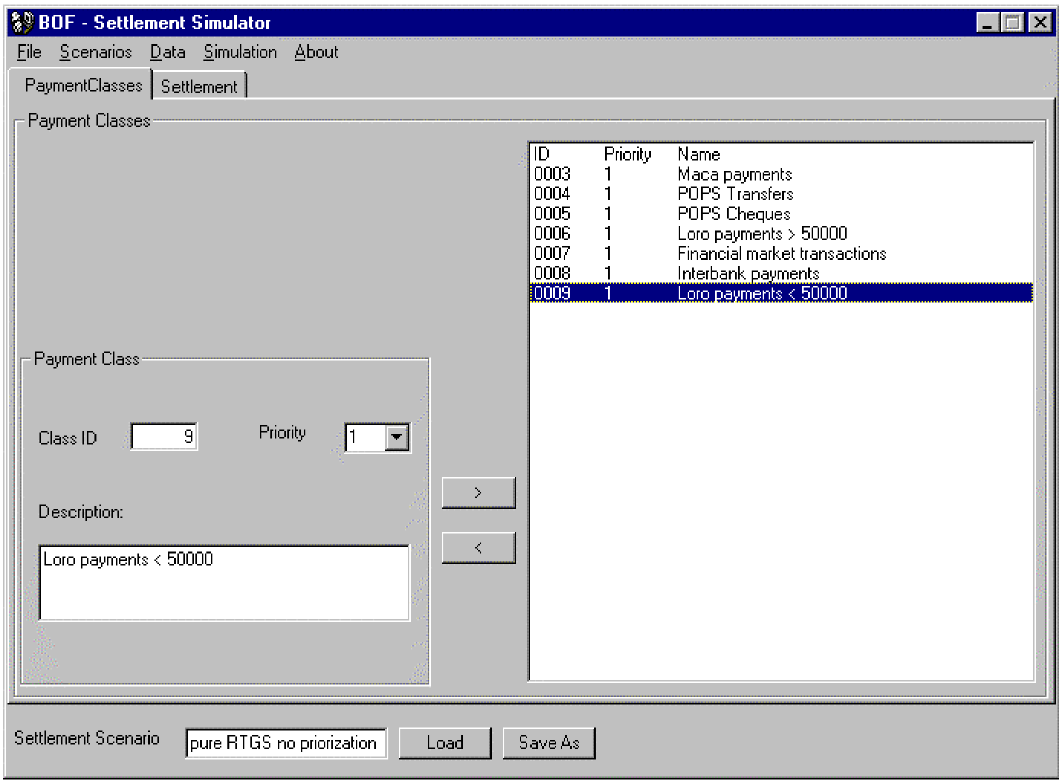
Caps Set Against: Bank 8

Gross Cap: 30

Net Cap: 60

Accountholder Scenario: DEMO

Figure 5. **View of settlement scenario: payment classes**



ID	Priority	Name
0003	1	Maca payments
0004	1	POPS Transfers
0005	1	POPS Cheques
0006	1	Loro payments > 50000
0007	1	Financial market transactions
0008	1	Interbank payments
0009	1	Loro payments < 50000

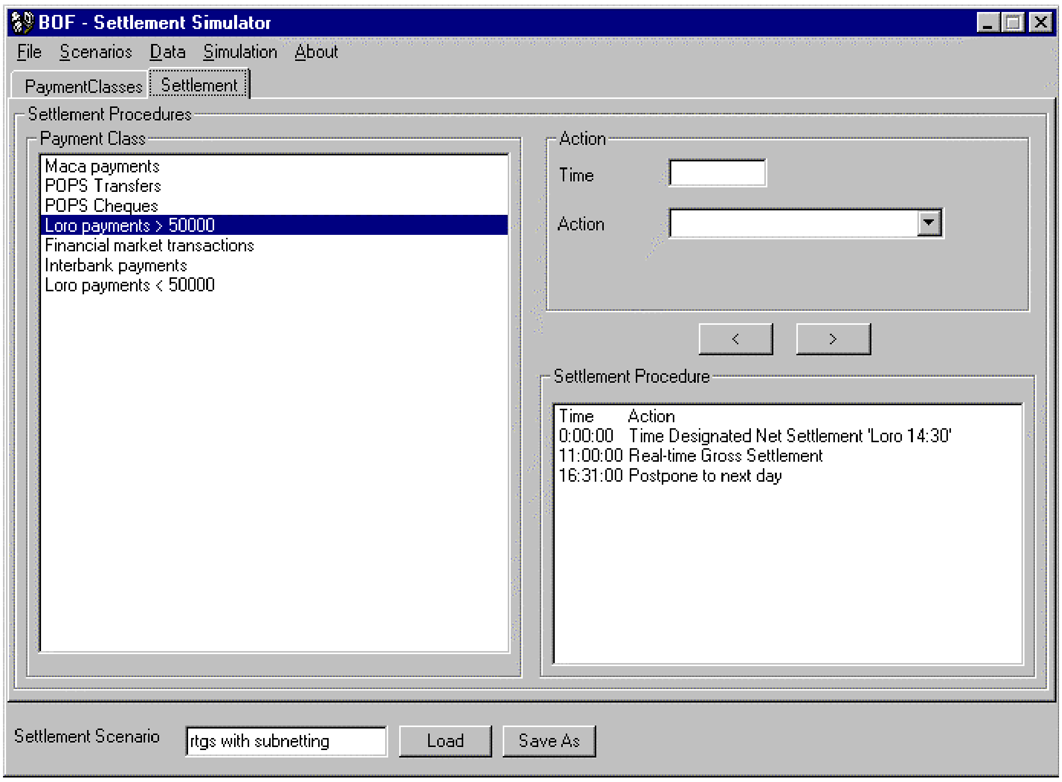
Class ID: 9

Priority: 1

Description: Loro payments < 50000

Settlement Scenario: pure RTGS no priorization

Figure 6. **View of settlement scenario: settlement of payments**



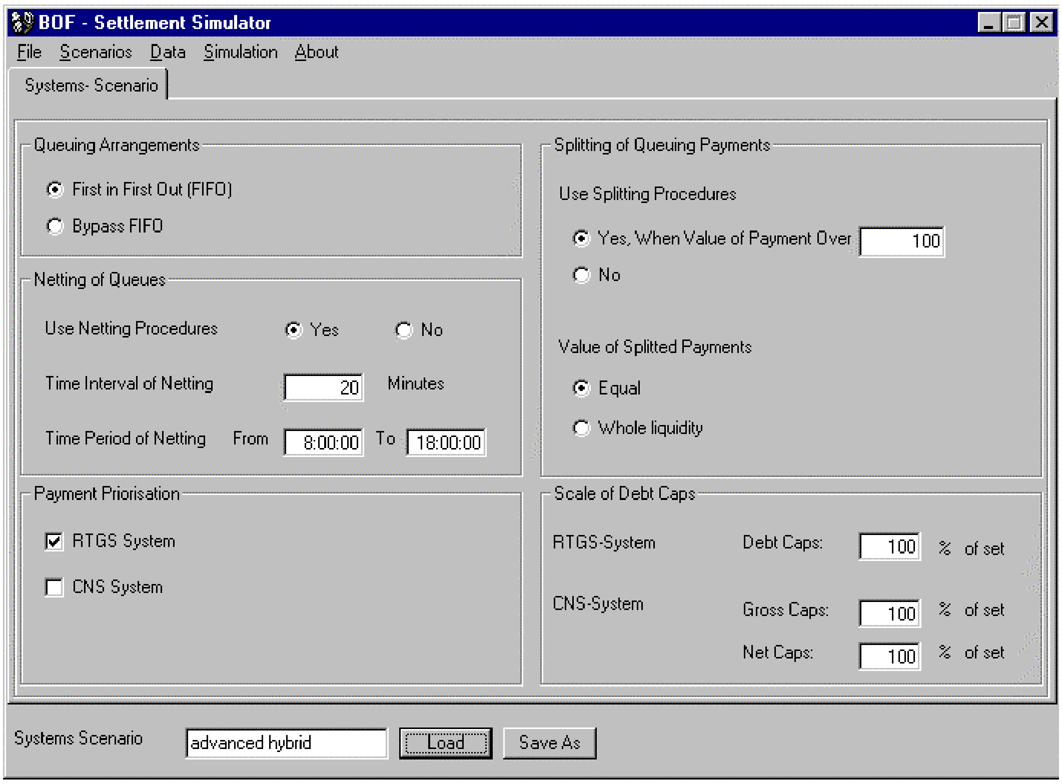
Payment Class:

- Maca payments
- POPS Transfers
- POPS Cheques
- Loro payments > 50000
- Financial market transactions
- Interbank payments
- Loro payments < 50000

Time	Action
0:00:00	Time Designated Net Settlement 'Loro 14:30'
11:00:00	Real-time Gross Settlement
16:31:00	Postpone to next day

Settlement Scenario: rtgs with subnetting

Figure 7. **View of systems scenario**



Queuing Arrangements

● First in First Out (FIFO)
○ Bypass FIFO

Netting of Queues

Use Netting Procedures ● Yes ○ No
Time Interval of Netting 20 Minutes
Time Period of Netting From 8:00:00 To 18:00:00

Payment Priorisation

☑ RTGS System
☐ CNS System

Splitting of Queuing Payments

Use Splitting Procedures
● Yes, When Value of Payment Over 100
○ No

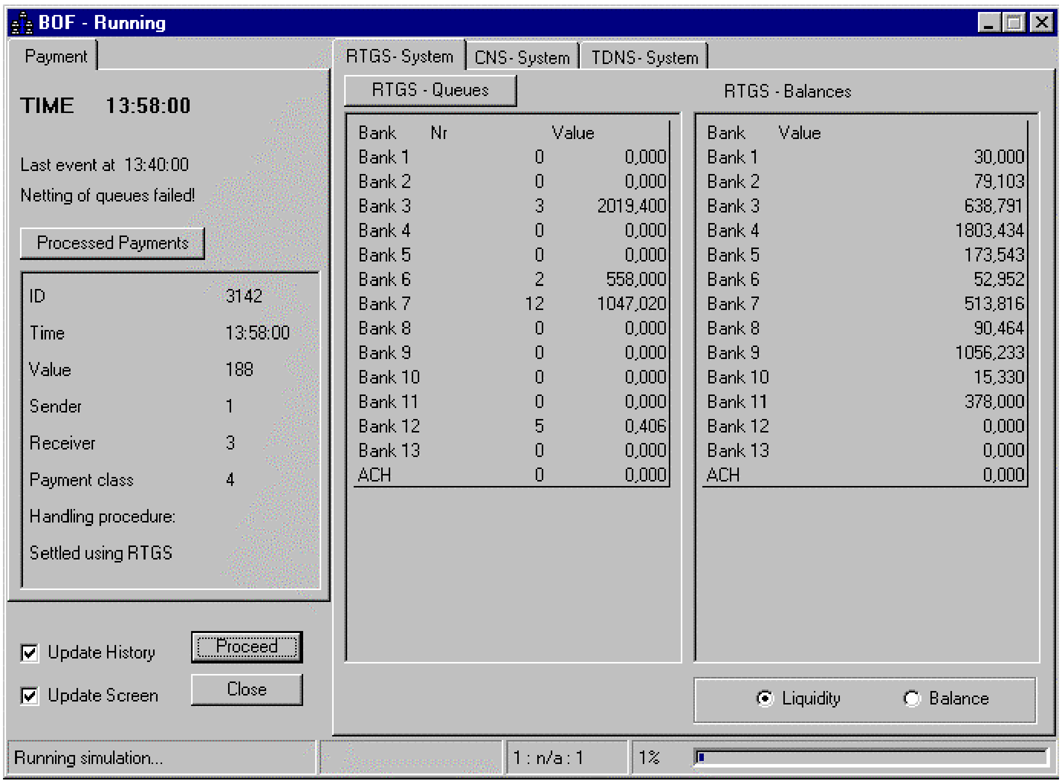
Value of Splitted Payments
● Equal
○ Whole liquidity

Scale of Debt Caps

RTGS-System Debt Caps: 100 % of set
CNS-System Gross Caps: 100 % of set
Net Caps: 100 % of set

Systems Scenario advanced hybrid

Figure 8. **Run-time view of simulator: RTGS system**



TIME 13:58:00

Last event at 13:40:00
Netting of queues failed!

ID	3142
Time	13:58:00
Value	188
Sender	1
Receiver	3
Payment class	4
Handling procedure:	
Settled using RTGS	

☑ Update History
☑ Update Screen

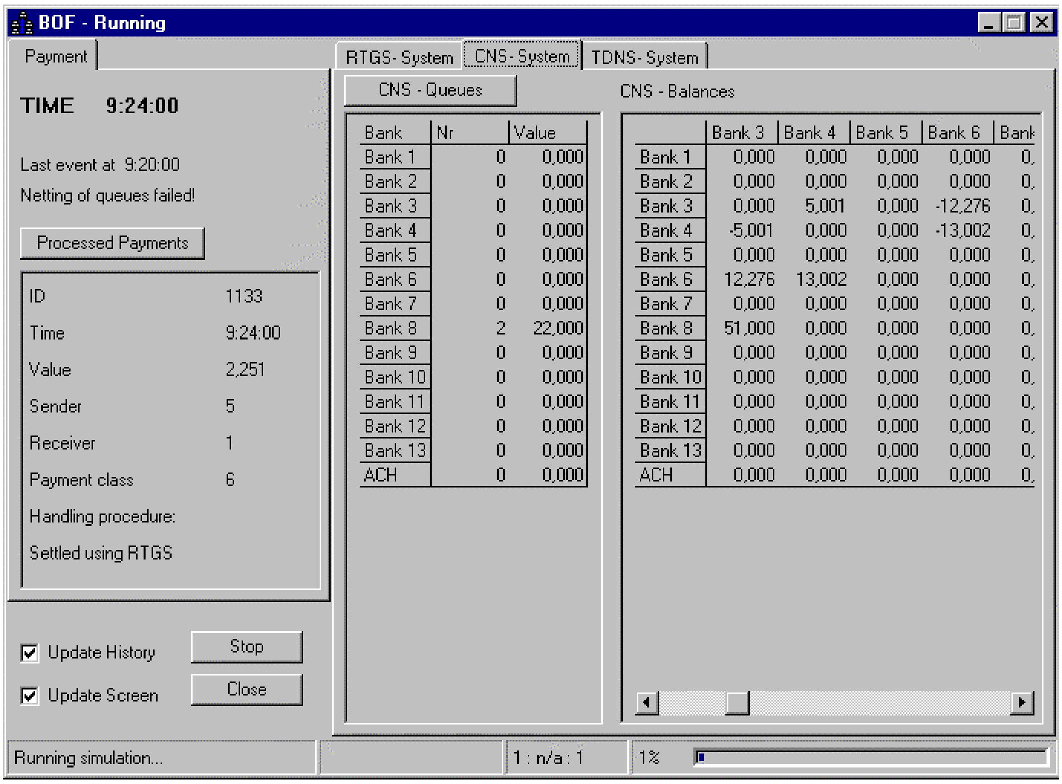
Bank	Nr	Value
Bank 1	0	0,000
Bank 2	0	0,000
Bank 3	3	2019,400
Bank 4	0	0,000
Bank 5	0	0,000
Bank 6	2	558,000
Bank 7	12	1047,020
Bank 8	0	0,000
Bank 9	0	0,000
Bank 10	0	0,000
Bank 11	0	0,000
Bank 12	5	0,406
Bank 13	0	0,000
ACH	0	0,000

Bank	Value
Bank 1	30,000
Bank 2	79,103
Bank 3	638,791
Bank 4	1803,434
Bank 5	173,543
Bank 6	52,952
Bank 7	513,816
Bank 8	90,464
Bank 9	1056,233
Bank 10	15,330
Bank 11	378,000
Bank 12	0,000
Bank 13	0,000
ACH	0,000

● Liquidity ○ Balance

Running simulation... 1 : n/a : 1 1%

Figure 9. **Run-time view of simulator: CNS system**



TIME 9:24:00

Last event at 9:20:00

Netting of queues failed!

ID	1133
Time	9:24:00
Value	2,251
Sender	5
Receiver	1
Payment class	6
Handling procedure:	
Settled using RTGS	

☑ Update History

☑ Update Screen

Bank	Nr	Value
Bank 1	0	0,000
Bank 2	0	0,000
Bank 3	0	0,000
Bank 4	0	0,000
Bank 5	0	0,000
Bank 6	0	0,000
Bank 7	0	0,000
Bank 8	2	22,000
Bank 9	0	0,000
Bank 10	0	0,000
Bank 11	0	0,000
Bank 12	0	0,000
Bank 13	0	0,000
ACH	0	0,000

CNS - Balances

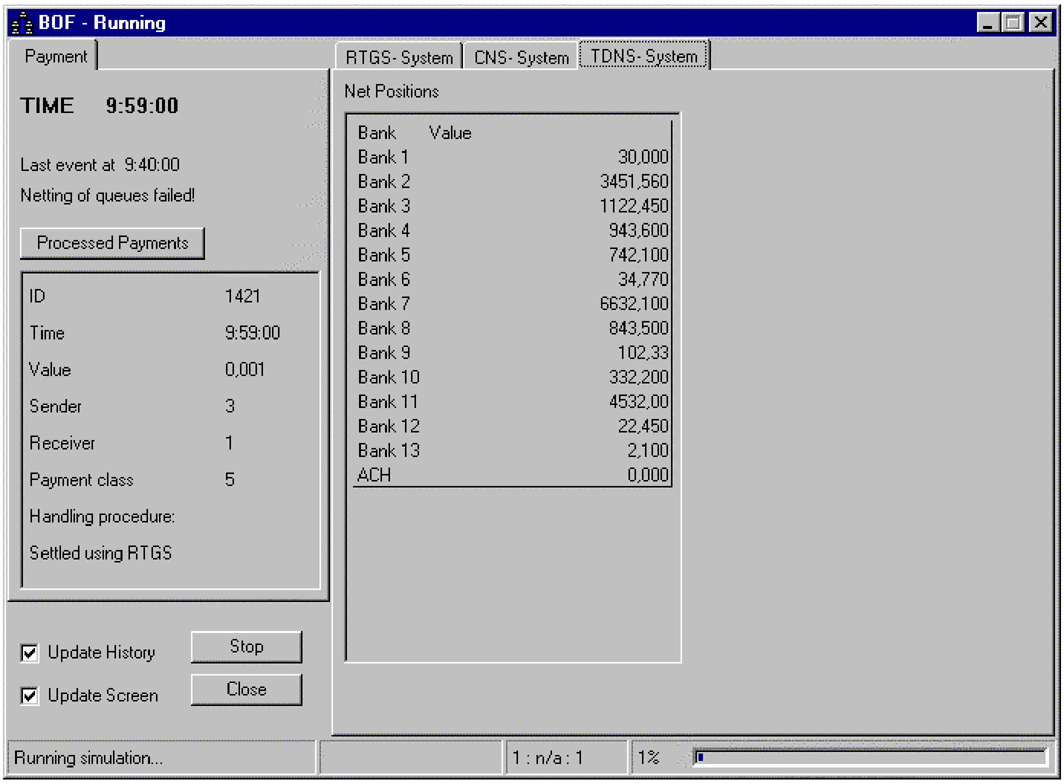
	Bank 3	Bank 4	Bank 5	Bank 6	Bank
Bank 1	0,000	0,000	0,000	0,000	0,
Bank 2	0,000	0,000	0,000	0,000	0,
Bank 3	0,000	5,001	0,000	-12,276	0,
Bank 4	-5,001	0,000	0,000	-13,002	0,
Bank 5	0,000	0,000	0,000	0,000	0,
Bank 6	12,276	13,002	0,000	0,000	0,
Bank 7	0,000	0,000	0,000	0,000	0,
Bank 8	51,000	0,000	0,000	0,000	0,
Bank 9	0,000	0,000	0,000	0,000	0,
Bank 10	0,000	0,000	0,000	0,000	0,
Bank 11	0,000	0,000	0,000	0,000	0,
Bank 12	0,000	0,000	0,000	0,000	0,
Bank 13	0,000	0,000	0,000	0,000	0,
ACH	0,000	0,000	0,000	0,000	0,

Running simulation...

1 : n/a : 1

1%

Figure 10. **Run-time view of simulator: TDNS system**



TIME 9:59:00

Last event at 9:40:00

Netting of queues failed!

ID	1421
Time	9:59:00
Value	0,001
Sender	3
Receiver	1
Payment class	5
Handling procedure:	
Settled using RTGS	

☑ Update History

☑ Update Screen

Net Positions

Bank	Value
Bank 1	30,000
Bank 2	3451,560
Bank 3	1122,450
Bank 4	943,600
Bank 5	742,100
Bank 6	34,770
Bank 7	6632,100
Bank 8	843,500
Bank 9	102,33
Bank 10	332,200
Bank 11	4532,00
Bank 12	22,450
Bank 13	2,100
ACH	0,000

Running simulation...

1 : n/a : 1

1%

Appendix 3. The Finnish interbank payment system

1 Facilities provided by the Bank of Finland

1.1 Settlement accounts

The Bank of Finland offers authorized credit institutions a settlement account in the real-time gross settlement system, the BoF-RTGS system. To facilitate the settlement of their own and customers' payments, credit institutions maintain settlement accounts at the Bank of Finland. In addition to banks, certain other institutions[1] maintain settlement accounts at the Bank of Finland to execute funds transfers.

1.2 Liquidity credit

In order to promote the smooth operation of the RTGS system, the Bank of Finland provides liquidity credit to credit institutions participating in the BoF-RTGS system. Presently, the maturity of a liquidity credit is one day, and it must be fully collateralized. The institutions mentioned in footnote 1 are not entitled to intraday credit.

1.3 BoF-RTGS system

The BoF-RTGS system has been in operation since March 1991. It is owned, administered and supervised by the central bank. The BoF-RTGS system is a real-time credit transfer system in which the sender of funds initiates the transfer. It is a decentralized system consisting of two subsystems

1 Bank of Finland's settlement account application and
2 account holders' multi-user workstation application.

The Bank of Finland’s settlement account application and the workstations are linked together via a telecommunications network. Account holders may also, since October 1998, enter payment orders into the BoF-RTGS system via the SWIFT network.

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[1] Other institutions holding settlement accounts are the Finnish Central Securities Depository (FCSD/APK), State Treasury and the government’s Assset Management Company Arsenal

Payment transfers entered by account holders and the Bank of Finland are settled in real time in the Bank of Finland’s settlement account database. If there is insufficient cover on the account of the sender, a payment transfer remains unsettled. The system provides queuing facilities, in which payments can be cancelled, moved or assigned priority status and earliest settlement times.

The BoF-RTGS system entails immediate finality. Payment transfers entered into the system are final as soon as they are settled. Completion of settlement means that funds are debited to the sender’s account and credited to the receiver’s account. Payments are not revocable after settlement. Errors are corrected by offsetting transfers.

In 1997 turnover in the BoF-RTGS system was FIM 9 013.2 billion (ECU 1 497.2) and the number of transactions 100 900. The turnover was about 15 times Finland’s gross domestic product.

2 Settlement procedures

The Finnish payment system is currently moving to increased use of gross settlement. The payment structure and policy presented here are the RTGS-with-subnetting and Hybrid structures. The RTGS-with-subnetting structure is the system that was in effect in May 1997, when the payment data for the simulations was collected. The Hybrid structure will be put into effect at the start of 1999.

The settlement procedures for various payment classes in both systems are summarized in table 1. There are two systems for executing domestic interbank payments for retail and corporate customers. PMJ payments include retail payments of smaller value such as giros, reference giros, recurrent payments, direct debits, card debits, and ATM transactions. POPS payments are large-value express transfers, cheques or bank drafts. Loro payments are markka-denominated foreign payments. Payments other than those found in table 1 are settled by RTGS in both systems.

Table 1. RTGS-with-subnetting and Hybrid settlement scenarios

	RTGS with subnetting	Hybrid
PMJ payments	PMJ net settlement at 15:45	net settlements during the night and at 15:45
POPS payments	within Interbank (PMJ) net settlement	Over limit: RTGS Under limit: CNS
Loro payments	net settlement at 14:30	> ECU 8 300: RTGS < ECU 8 300: within PMJ net settlements
Financial markets-transactions	net settlement at 13:00	RTGS

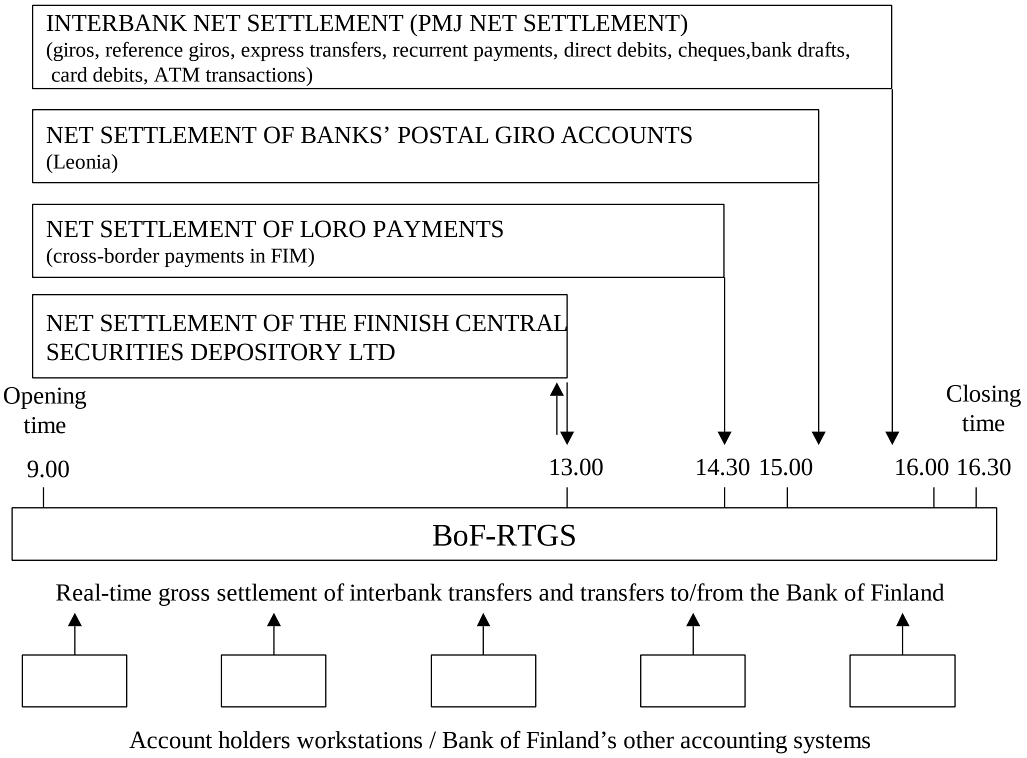
2.1 RTGS-with-subnetting structure

The RTGS-with-subnetting structure is the settlement structure and policy in effect in May 1997. Here, the BoF-RTGS system has been used mainly for real-time gross settlement of interbank and central bank transfers.

The largest category of (gross) transactions consists of payments between banks related to money market and foreign exchange trades and to interbank lending. The second largest category comprises funds transfers between the Bank of Finland and the banks, mainly in connection with open market operations and cash deliveries between the Bank of Finland and the banks. The third category consists of net settlements of various netting systems (see figure 1). The netting systems in use were:

1. interbank net settlement (PMJ net settlement)
2. net settlement of banks’ postal giro accounts
3. net settlement of loro payments (markka- denominated foreign payments)
4. net settlement of securities transactions within the Finnish Central Securities Depository Ltd.

Figure 1. **RTGS-with-subnetting structure: Finnish payment system structure in effect in May 1997**

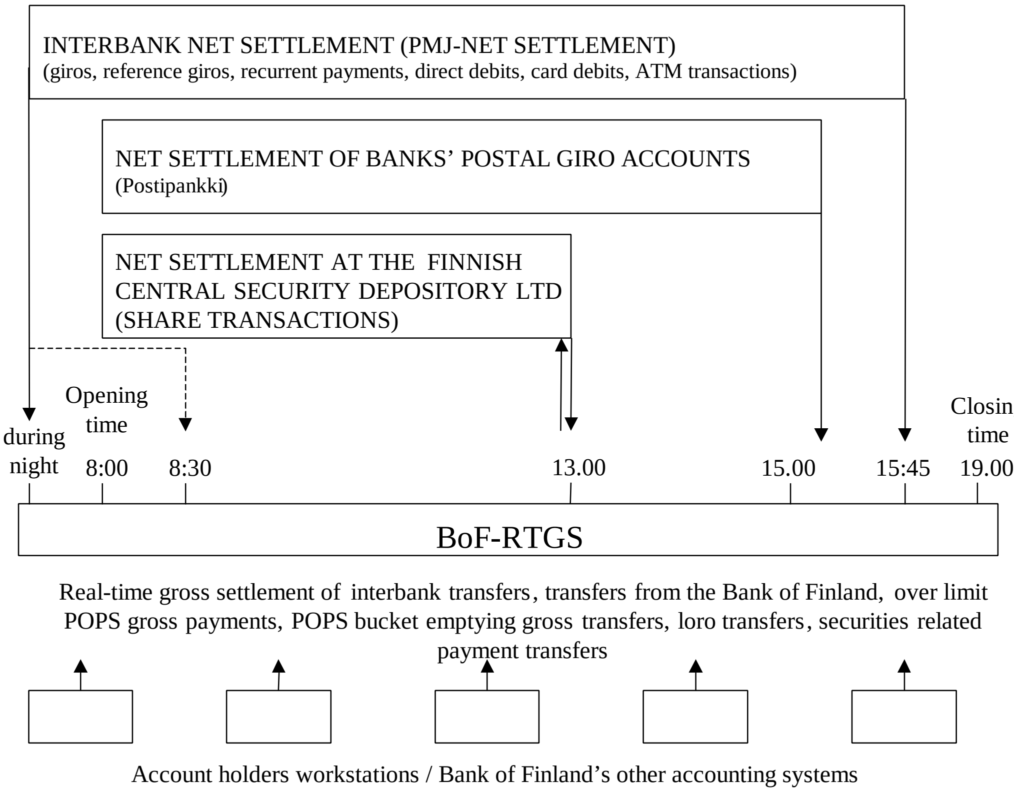


Certain securities-related payments are settled on a gross basis, but no customer payments are settled on a gross basis in the RTGS-with-subnetting structure.

2.2 Hybrid structure

The Hybrid structure is the EMU-compatible settlement structure and policy that will enter into effect at the start of 1999. It will be put into effect for the most part already at the end of 1998.

Figure 2. **Hybrid structure: EMU-compatible payment system structure in 1999**



In the Hybrid settlement structure, certain customer payments are also processed and the following types of payments are settled on a gross basis via the BoF-RTGS system:

- transactions constituting of payments between banks and related to money market or foreign exchange trades and interbank lending,
- funds transfers between the Bank of Finland and the banks mainly in connection with open market operations and maintenance of the currency supply
- certain POPS payments
- securities-related transactions
- loro payments

In the Hybrid structure, most express transfers and cheques are settled in the POPS system. In the POPS system, banks apply bilateral limits so that payments with a value less than the limit are settled bilaterally. Larger payments are settled on a gross basis in the BoF-RTGS system. A more detailed explanation of the POPS settlement system is given in section 3.

Also in this structure, securities-related transactions are no longer settled in the Finnish Central Securities Depository but are instead handled on a gross basis. Also the loro net settlement has ended and all loro payments are settled on a gross basis in the BoF-RTGS system.

Thus the remaining net settlements are:

- interbank net settlement (PMJ net settlement)
- net settlement of banks' postal giro accounts

In the Hybrid settlement structure, there will be two PMJ net settlements: during the night before system opening and at 3.45 pm.

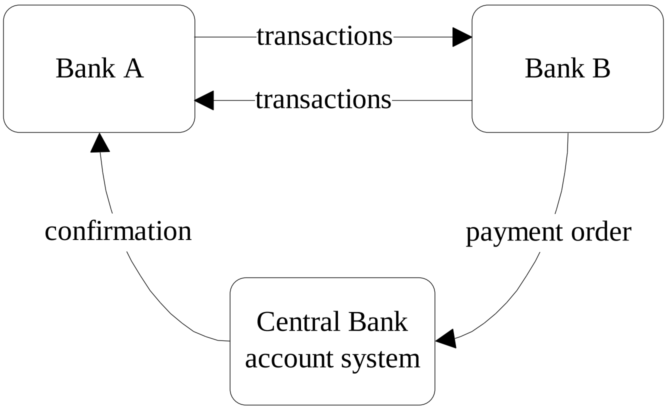
3 POPS settlement system

The POPS system is designed as a bilateral netting system. Banks participating in the POPS system send payment messages bilaterally to each other, without using a centralized clearing house or a clearing operator.

Banks control, via bilateral limits, the size of their bilateral net positions vs other participants. Two kinds of limits are applied, the RTGS limit and the credit limit. The RTGS limit is half of the bilateral credit limit.

The RTGS limit is the maximum size of a single payment that can be settled on a net basis. Larger payments will be settled on a gross basis. The RTGS limit also functions as a signal that triggers the settlement of bilateral net balances during the day. Whenever the amount of a bilateral credit exceeds the RTGS limit, the intraday settlement procedure is invoked, which means that the debtor party sends a settlement transaction via the BoF-RTGS system (see figure 3). Intraday settlement transactions are always equal in amount to the RTGS limit. The credit limit is the maximum allowable amount of a bilateral net balance. If the credit limit is reached, transactions that would increase the net balance are rejected by the risk-taking bank. Since these credit limits are not collateralized, the POPS system entails limited counterparty risk.

Figure 3. **Finnish POPS settlement system**



Settlement of POPS payments occurs in the BoF-RTGS system

- during the day whenever the bilateral net position exceeds the signal trigger of the RTGS limit
- during the day whenever the size of a single payment exceeds the RTGS limit
- at the end of the day bilateral balances are settled to zero.

The overall maximum credit risk accepted by any bank is the sum of its granted bilateral credit limits, but the risks are much smaller in effect due to the continuous settlement process and the continuous debit/credit changeovers in bilateral positions throughout the day. The payment information on all POPS payments, those that are settled bilaterally between the banks and those that are settled in BoF-RTGS, is exchanged between the banks.

In 1997 there were ten direct participants in the POPS system, of which four were foreign banks.[2]

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[2] Banks participating in the POPS system are Aktia Savings Bank Ltd, Bank of Åland Ltd, Den Danske Bank Helsinki Branch, Leonia Ltd (former Postipankki Ltd), Mandatum Bank Ltd (former Interbank Ltd), Merita Bank Ltd, Okobank, Skandinaviska Enskilda Banken Helsinki Branch, Svenska Handelsbanken AB, Branch Operation in Finland and Unibank A.S. Helsinki Branch

4 Transfer system operating hours

In the RTGS-with-subnetting structure, the BoF-RTGS system opens at 9.00 am each business day, with entries being made until the system closes at 4.30 pm. In the Hybrid structure, the BoF-RTGS system opens at 8 am and closes at 7 pm Finnish time.

Currently, the operating hours of the POPS system are from 8.00 am to 4.30 pm Finnish time, but they are likely to be extended in the near future.

Appendix 4. Input data

1 Actual Data

Although, in RTGS systems, payments are generally settled payment by payment, not all the payments covered here were reported individually. In respect of the smaller loro and POPS payments, which were reported only on an aggregate basis, estimates were made of individual payments. Because one of the participating banks did report all outgoing payments individually, we were able to use this data to extrapolate individual payments for the other banks. For this, we used the simple exponential function $a*b^x$. The constants a and b were estimated for each bank by means of exponential regression, using the value distributions provided by all the banks. The term x in the equation refers to a random variable with a value between zero and one. Payments were assumed to be uniformly spread over a 20-minute period.

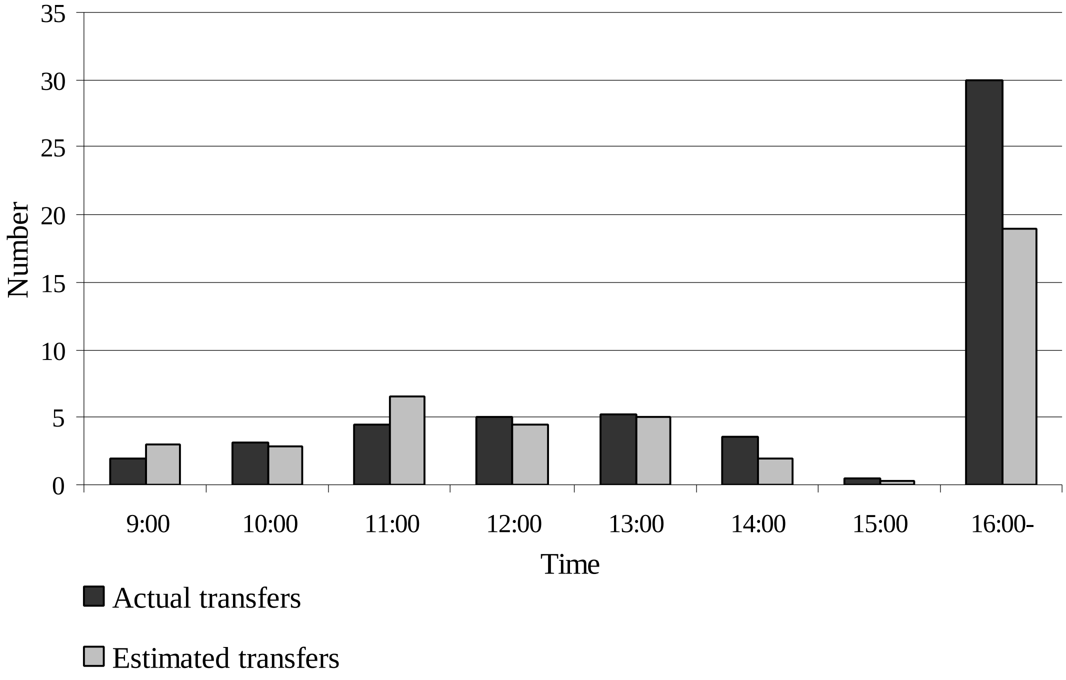
It was also necessary to adjust some of the banks' loro payment data so that bilateral loro clearing in the model would produce results similar to what actually happened during the four-day period.

After the data were adjusted, we tested them against the banks' accounts at the Bank of Finland. If discrepancies occurred between the two data sources, possible errors and omissions were checked with participating banks and corrected if possible. Some banks were asked to supplement the data they had previously reported. As most payments reported by the banks had not previously been settled via the RTGS system, this proved to be a large task. It is fair to assume that the data were sufficiently accurate for simulation purposes.

The reliability of the data on POPS payments could not be tested against existing systems as these payments had been settled via netting. Banks introduced POPS buckets (see appendix 3, section 3) on 14 May 1998. After data became available on actual numbers and values of POPS bucket transfers, the results produced by the simulations were compared with the data of June 1998.

In June the daily average number of actual POPS bucket transfers was six, which agrees with the results generated by the model for the four-day period. The average total value transferred per day in June was FIM 272 million and the corresponding value for the four-day simulations was FIM 220 million.

Figure 1. **Time distribution of number of POPS bucket transfers, actual (June 1998) and generated**



At the time of writing (October 1998) there are no other comparative data available.

2 Generated data

Because four days is a rather short period for making valid comparisons of different system structures, a procedure was developed for extrapolating for additional days. The number and order of transactions was varied so as to determine whether the results for the four days of actual data are stable and whether the same settlement behaviour can be expected for days that differ in this regard.

From figure 10 in the main text, it is apparent that the daily distribution of payments does not follow a simple formula. Because payments in each class can be settled in the simulator via different settlement systems, the best way to maintain the unique characteristics of the Finnish payment data was to generate additional days by sampling from the pool of actual payment data. In this way, the daily distribution of numbers in each payment class is kept, on average, the same as for the actual payment data.

The exact procedure for generating additional days is illustrated in figure 2. First, the number of payments for each day is selected randomly from a normal distribution with mean and standard deviation the same as for the actual four days of data. From figure 3 one can see that this is a fairly good approximation. The number of payments in each hour in the generated and actual data are the same fractions of the total number of payments during the day.

Figure 2. **Overview of the process of generating payment data**

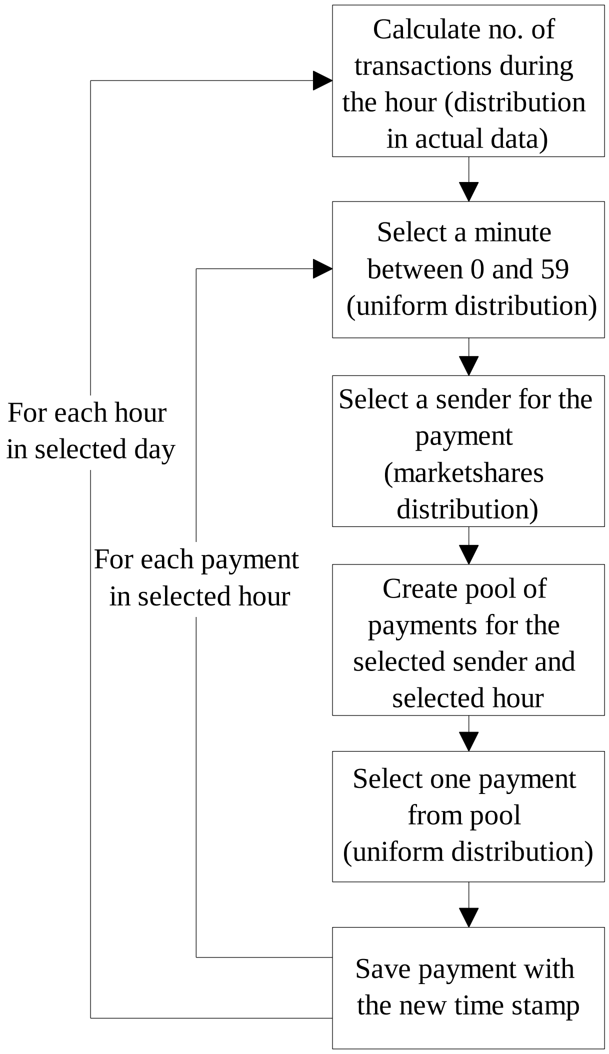
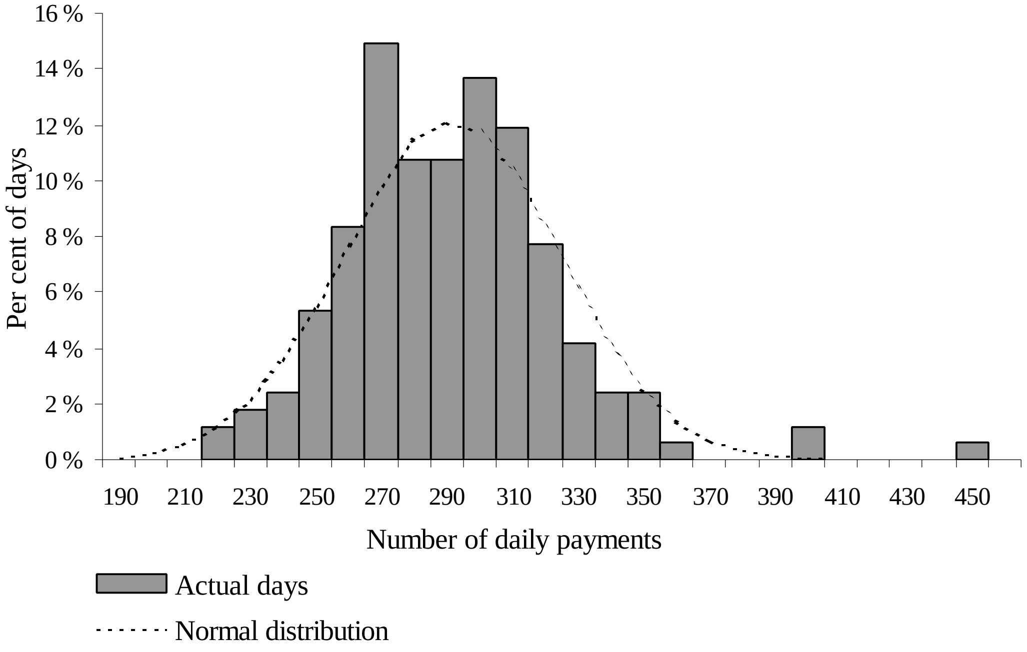


Figure 3. **Distribution of daily number of payments in the BoF-RTGS system, 1 July 1997 – 29 May 1998**



Since the payments are sampled from hourly pools, only the time stamp for each payment need be generated randomly. It is assumed that there are no concentrations of payments, eg at the start or end of the hour, and so a uniform distribution was used. This proved to be a reasonable assumption on the basis of information collected from the settlement account system after the Hybrid structure was for the most part in operation in late 1998. The intra-minute distribution of all but loro payments was found to be approximately uniform. A large share of loro payments are entered into the system just after opening. In the simulations, these payments were treated as payments entered into the system prior to opening.

After selecting the time stamp for the payment, an account holder is selected randomly in accord with the distribution of the number of payments. An actual payment is then randomly selected from the hourly pool of payments sent by the selected account holder. The generated payment has the same value, payment class and receiver as the selected actual payment.

Sampling the payments implies that, for each account holder and payment class, the generated mean value and settlement time mimic the actual situation. The sample drawings continue until the appropriate number of generated payments is obtained for the particular hour. The ratio of hourly generated payments to daily total is the same as for the actual payments. Altogether, the data consist of about 16 000 individual payments amounting to over FIM 216 billion (ECU 35.9 bill.).

Appendix 5. Glossary

Automated Clearing House (ACH)	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.
Batch	The transmission or processing of a group of payment orders and/or securities transfer instructions as a set at discrete intervals of time.
Bilateral net settlement system	A settlement system in which participants' bilateral net settlement positions are settled between every bilateral combination of participants.
Bilateral netting	An arrangement between two parties to net their bilateral obligations. The obligations covered by the arrangement may arise from financial contracts, transfers or both.
Caps	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.
Central bank liquidity facility	A standing credit facility that can be used by certain designated account holders (e.g. banks) at the central bank. In some cases, the facility can be used automatically at the initiative of the account holder, while in other cases the central bank may retain some degree of discretion. The loans typically take the form of advances or overdrafts on an account holder's current account which may be secured by a pledge of securities (also known as lombard loans in some European countries), of traditional rediscounting of bills or of repurchase agreements.
Clearing system	A set of procedures where financial institutions present and exchange data and/or documents relating to funds or securities transfers to other financial institutions.
Collateral	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.
Counterparty	The opposite party in a financial transaction (e.g. in a transaction with the central bank).

Credit institution	The definition given to a "bank" in the European Union. The First EC Banking Co-ordination Directive defines it as an undertaking whose business is to receive deposits or other repayable funds from the public and to grant credits.
Credit risk/exposure	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.
Credit transfer	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.
Cross-border payment	Payments transferred from one currency area to another.
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.
Non-bank financial institution	A financial institution that does not come under the definition of a "bank" (e.g. a financial institution other than a credit institution in Europe).
Obligation	A duty imposed by contract or law. Obligation is also used to describe a security or other financial instrument, such as a bond or promissory note, which contains the issuer's undertaking to pay the owner.
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.
Payment order/instruction	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.
Payment system	A payment system consists of a set of instruments, banking procedures and, typically, interbank funds transfer systems that facilitate the circulation of money.
Payment versus payment (PVP)	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.
PMJ	The Banks’ Payment Clearing System in Finland. It is operated by the banks and covers both small and large value payments.
POPS	Data transmission and clearing system for express transfers and large-value cheques in Finland.
Queuing	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.
Real-time gross settlement system (RTGS)	A gross settlement system in which processing and settlement take place in real time (continuously).
Real-time transmission, processing or settlement	The transmission, processing or settlement of a funds or securities transfer instruction on an individual basis immediately after the time it is initiated.

Retail funds transfer system	A funds transfer system which handles a large volume of payments of relatively low value in such forms as cheques, credit transfers, direct debits, ATM and EFTPOS transactions.
Retail payments	Mainly consumer payments of relatively low value and low urgency.
Same day funds	Money balances that the recipient has a right to transfer or withdraw from an account on the day of receipt.
Settlement	An act that discharges obligations in respect of funds transfers between two or more parties.
Settlement account	An account held by a direct participant in the national RTGS system with the central bank for the purpose of processing payments.
Settlement institution	The institution across whose book transfers between participants take place in order to achieve settlement within a settlement system.
Settlement lag	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.
Settlement risk	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.
Settlement system	A system used to facilitate the settlement of transfers of funds or financial instruments.
Solvency risk	The risk of loss due to the failure (bankruptcy) of an issuer of a financial asset or due to the insolvency of the counterparty.
Systemic risk	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 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.
Unwinding	A procedure followed in certain clearing and settlement systems in which transfers of securities or funds are settled on a net basis, at the end of the processing cycle, with all transfers provisional until all participants have discharged their settlement obligations. If a participant fails to settle, some or all of the provisional transfers involving that participant are deleted from the system and the settlement obligations from the remaining transfers are then recalculated. Such a procedure has the effect of transferring liquidity pressures and possibly losses from the failure to settle to other participants, and may, in an extreme case, result in significant and unpredictable systemic risks.
Value date	The date on which a transaction is settled. The settlement might take place on the same day as the trade (same-day settlement) or can occur one or several days after the trade (the value date is specified as T + the settlement lag).
Zero-hour clause	A provision in the bankruptcy laws of some countries which may retroactively render transactions of a closed institution ineffective after 0.00 a.m. on the date the institution is ordered to be closed.

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

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