Bank of Japan Working Paper Series No. 05-E-**
2005

Initial Funding Levels for the Special Accounts in the New BOJ-NET*

Kei Imakubo†
Bank of Japan
and
James J. McAndrews‡
Federal Reserve Bank of New York

<u>PRELIMINARY and INCOMPLETE</u>

Abstract

The Bank of Japan plans to enhance its own pure RTGS system, the BOJ-NET, to a queue-augmented RTGS system, with queuing and offsetting mechanisms. We investigate the performance of the planned BOJ-NET using the simulation analysis on ten days' historical data, i.e. how the level of the initial balances change the speed of settlement based on three main scenarios and more than ten sub scenarios. Our results show that the more the total balances the more quickly the settlement occurs in general, however that raising the initial balances does not necessarily result in quickening the settlement if not maintaining the efficient distribution of balances across participants. We also find that there are economies of scale in Japan in combining three large-value payment systems rather than maintaining separate systems.

---

* We would like to thank to Masayuki Mizuno (the Bank of Japan) for his encouragement and fruitful advice, as well as other colleagues at the Bank of Japan. Of course, any remaining errors should be solely attributed to the authors. The views expressed in this paper are those of the authors and do not necessarily reflect those of the Bank of Japan or the Federal Reserve Bank of New York or the Federal Reserve System.
† Payment and Settlement Systems Department, Bank of Japan. kei.imakubo@boj.or.jp
‡ Payments System Studies, Federal Reserve Bank of New York. jamie.mcandrews@ny.frb.org

1. Introduction

The Bank of Japan plans to develop a new generation of the Bank of Japan Financial Network System (BOJ-NET), its primary large-value payment system. The new system will incorporate payments from three different streams of current payment activities, two of which now settle toward the end of the processing day in designated-time net settlement systems. The new system will allow for intraday settlement on a real-time gross settlement (RTGS) basis. One of the primary motivations for the development of the new system is to quicken the settlement of large-value payments relative to the current pattern, and to reduce intraday settlement exposure of those payments.

Much of the design work for the new system is already completed, while many decisions related to the implementation still remain. In this paper, we focus on one aspect of the new system, the funding levels of special accounts that will be drawn on to effect settlement throughout the day in a "liquidity-saving" mode. We examine the constraints on funding that will likely be needed to achieve settlement of a high proportion of payments expected to be included in the settlement using this mode. We first maintain the assumption that no additional funding from current accounts will be added to the special accounts during the day except for at the end of the day, and the assumption that each participant's special account balance must always remain non-negative throughout the day.

In general, there is a strong trade-off between the rate of settlement of a group of payments, and the level of funding devoted to those settlement. With large levels of funding, settlement can be made more quickly. First then, the level of funding of initial balances is important in establishing how much value is settled prior to the end of the settlement period. Once the level of funding is determined, participants can seek to optimize the distribution of initial balances across participants. The optimum distribution of balances across participants leads to the greatest value of settlement within the settlement period for that total level of funding used.

A characteristic of the optimum distribution of balances across participants is that additional balances placed in any participant's account yield equal increases in amounts settled. This "equalization of marginal benefits" is a characteristic common to many economic allocation problems.

We simulate the performance of the new BOJ-NET using several levels of initial balances for the special accounts. We examine how changes in levels of initial balances affect the value of payments settled, the amounts left unsettled after a particular time (16:00), and the average time of settlement. This information can be useful to participants and planners in seeking the right balance between the value settled during the day, and the liquidity saving potential of the new BOJ-NET. We also conduct some simulations examining how small changes in initial balances by some particular participants affect the outcomes, and how additional funding on the special accounts affects the outcomes, relaxing the assumption that no additional funding is added during the day. Finding the local optimum distribution of balances using simulations on historical data would require a large number of simulations.

An additional issue that we explore is whether the plan to combine into the new BOJ-NET the payments that are currently settled on the Foreign Exchange Yen Clearing System (FXYCS), the large-value payments on the Zengin Data Telecommunication System (Zengin System), and most payments on the current BOJ-NET will yield liquidity-saving effects. It is plausible to think that maintaining separate systems might require less liquidity, or might result in speedier settlement for a given level of liquidity. If combining the systems is liquidity-saving, then we can say that there are liquidity complementarities among the three systems to be combined. As we demonstrate, strong liquidity complementarities do exist among the three systems.

This paper is organized as follows. We begin in Section 2 by briefly describing the current large-value payment landscape in Japan, and how the design of the new BOJ-NET is expected to alter that landscape. We also provide a rough planned description of the new BOJ-NET and explain the purpose of the special account and its funding. In section 3 we describe the problem of finding optimal funding levels, and in Section 4 we present our results. In section 5 we examine the changes in liquidity efficiency of combining the two new payments streams with the payments on the current BOJ-NET. In section 6 we provide a short summary and conclusion.

2. Large-value payments in Japan

2.1 Current structure of large-value payments

The new BOJ-NET plans to incorporate payments currently made on the BOJ-NET, the FXYCS, and the large-value payments on the Zengin System. We briefly describe some aspects of these three systems.[1]

---

[1] See BIS [2003] for more detailed descriptions of the three systems.

The BOJ-NET is an RTGS system. It settles both Japanese Government Bonds (JGBs) and funds transfers. The latter mainly consists of money-market transactions, but also includes the payments for various clearing securities settlement systems that use the BOJ-NET to transfer the net obligations and the cash legs. In addition, the money-market operations of the Bank of Japan are carried out using the BOJ-NET. There are only a few third-party, or customer, payments settled on the BOJ-NET, and these are very high value payments, indicating that these are also money-market transactions conducted by financial institutions that do not have current accounts with the Bank of Japan.

Settlement amounts on the BOJ-NET in March 2005 indicate that, on a daily average basis, the BOJ-NET settled 21,543 transfers with a total value of 88.9 trillion yen. The daily average value per settlement was 4.1 billion yen. Of these, money-market transactions totaled approximately 7,521 transfers with a total value of 39.3 trillion yen. The daily average value per settlement for these transactions was 5.2 billion yen.

The FXYCS is basically a designated-time net settlement (DNS) system that handles yen payments to settle foreign exchange trades. It conducts final settlement at 14:30 using the BOJ-NET. The FXYCS has not only a DNS mode but also an RTGS mode, although its use, including settlement of CLS related transactions, is rather limited. The volume and value of its daily average activities in March 2005 indicates that the two modes together settled 28,439 transactions per day, with a total value of 16.5trillion yen. The average value per transactions was 0.6 billion yen. The net amount transferred on the BOJ-NET in March 2005 averaged 2.1 trillion yen.

Finally, the Zengin System is also a DNS system, whose final settlement takes place at 16:15. In March 2005, the Zengin System averaged 5.1 million transactions per day, with a total daily average value of 11.0 trillion yen. The average size of payment was 2.2 million yen. It is mainly used for consumer and commercial payments. On average, the daily settlement amounts made through the BOJ-NET were 1.0 trillion yen per day in March 2005. It is estimated that roughly two-thirds of the value transferred on the Zengin System, approximately 7 trillion yen per day, were payments that were larger than 0.1 billion yen.

2.2 Future structure of large-value payments

The new BOJ-NET plans to operate as a queue-augmented RTGS system, with queuing and offsetting mechanisms.[2] As a sub account to the current account, a "special account" will be newly introduced. Participants will be able to designate their payment instructions to be settled either via their current accounts, on which collateralized overdrafts will remain available, or via their special accounts, which will not offer overdraft capability but offer queuing and offsetting mechanisms (see Imakubo [2005]). The intent of both the participants and the Bank of Japan is for most of the three payment streams just described to be settled via the special accounts. In addition to the special account, the current account will still operate, and is intended to be used for the Bank of Japan's own money-market operations, and for the settlement for various ancillary systems. For the settlement of JGBs trades, a unique liquidity-saving facility called the "simultaneous processing of Delivery-versus-Payment and collateralization (SPDC)," will be also available on another sub account of the current account.[3]

The new BOJ-NET will operate the special accounts as follows. The special accounts will be funded by the participants each morning at the start of the processing day (9:00) with an infusion of funding from their current accounts. That establishes the participants' initial balances in the special accounts (the special accounts will have a zero balance overnight). The participants will submit payment instructions to the special accounts, and if funds are sufficient, the payment instructions will be settled immediately via RTGS. If the funds are not sufficient, the payment instruction will be placed in a centralized queue. A queue management algorithm will continuously attempt a search for bilaterally offsetting payments (on a bypass-FIFO basis), for example, with each addition to any counterpart participant's pending payments in the queue. If a bilaterally offsetting payment is found, and if funds are sufficient to settle the payments simultaneously, settlement takes place. Once every hour, a multilateral offsetting algorithm running on a FIFO basis will find a set of payments that can be settled using available balances.[4] See the appendix for the details of bilateral and

---

[2] See BIS [1997], McAndrews & Trundle [2001], and BIS [2005] for the basic idea of the queue-augmented RTGS. See also Angelini [1998], Roberds [1999], and Bech & Garratt [2003] for the theoretical analysis of participants' behavior in the RTGS system.

[3] In the case of JGBs purchases, a buying participant is able to do the following four operations at the same time: 1) receive JGBs from a seller; 2) post these JGBs to the Bank of Japan as collateral for an intraday overdraft; 3) draw the intraday overdraft from the Bank of Japan; and 4) pay for the JGBs received from the seller with the intraday overdraft. A selling participant is able to do the following at the same time: 1) receive the pledged JGBs from the Bank of Japan; 2) deliver these JGBs to a buyer; 3) receive from the buyer the proceeds from the JGBs sold; and 4) repay the intraday overdraft to the Bank of Japan with the proceeds received from the buyer.

[4] The multilateral offsetting algorithm will include all queued payments in the initial offsetting, and successively drop the *latest* submitted payment from the participant with the largest funding shortfall

multilateral offsetting algorithms.

The participants will be able to transfer funds between their special accounts and their current accounts freely throughout the day as necessary.

It is assumed that, toward the end of the processing day, at 16:00, the participants will learn the amount that are not yet to be settled out of the queue of remaining payments in the special accounts. They will have 30 minutes left in which to submit additional funds to settle those remaining payments. The payments will be rejected if insufficient funds are submitted to the special accounts by 16:30. The current account will remain open until 17:00, while CLS users can use it until 19:00.

3. Initial funding levels

The funding levels in the special account will be determined by a choice of the participants. In general, the higher the funding levels, the greater the proportion of those payments that are submitted to the special account can be settled. In addition, the higher the funding levels, the more quickly will the settlement occur.

A feature of the new BOJ-NET is that funding can be supplied from the current account at any time of the day. To some degree, this option simplifies the problem for the participants of how much funding to transfer to the special account at the start of processing day, as any shortfalls or overages in funding can be corrected during the day if necessary.

When designing a payment system that uses a pure RTGS mode of operation as well as a queuing and offsetting mode of operation, one question the designers face is whether to create a second account, as in the new BOJ-NET's special accounts. An alternative is simply to rely on one current account, and have participants decide on the priority of the payment, that is to decide whether to send the payment in the pure RTGS mode or in the liquidity-economizing mode. The liquidity-economizing mode then relies on incoming funds over a period of time as well as offsetting. Such an alternative is described and discussed by Johnson, McAndrews and Soramäki [2004]. In the case of the new BOJ-NET, the computational requirements of the system would be reduced considerably with the introduction of the special accounts.

---

until a set of payments that have no funding shortfalls is found. Bech and Soramäki [2001] show that the algorithm, which successively drop the *largest* payment from the participant with the largest funding shortfall, finds the largest set of payments that can be settled using the multilateral offsetting given that one breaks the FIFO ordering rule.

The efficiency of the new BOJ-NET could potentially be negatively affected if the participants were to transfer funds into and out of their special accounts often during the day. The multilateral offsetting algorithm, for example, might not find many payments that can be settled if some participants had withdrawn funds immediately prior to the operation of the algorithm. Because of this potential negative effect of rapid and frequent changes in funding levels, it may be useful to investigate the following thought experiment. Suppose, contrary to the design of the new BOJ-NET, that the participants can fund their special accounts only twice during the day, at the opening of processing day and for the settlement of their unsettled queued payment instructions at 16:00. Under that counterfactual assumption, what would be efficient levels of initial funding?

There is a range of levels of efficient initial funding. Higher levels of efficient initial funding are associated with a faster rate of intraday settlement, and a higher proportion of settlement of payments prior to 16:00. There is a trade-off between more initial funding and a faster rate of intraday settlement, and a trade-off between initial funding and higher values of unsettled payments at 16:00. There is no clear answer to the question of how to value an increased rate of intraday settlement as there is no easily observable intraday rate of interest that would provide a benchmark level of benefit for a faster rate of intraday settlement, and a benchmark level of cost of intraday funds to remain in the special accounts during the day. Similarly there is no clear measure of the increase in credit and liquidity risk caused by leaving more payments unsettled until 16:00.

In the following exercises, we investigate levels of initial funding that are sufficiently high so as to quicken the overall settlement of large-value payments in Japan. In addition, we investigate funding levels high enough to assure that the level of unsettled payments at 16:00 is no greater than it is in today's large-value payment systems.

Consider the following problem.

$$\min \sum_i b_i \text{ , subject to } \{P_{ij}\}, \quad \forall i, j; \quad i \neq j$$

$$b_i \geq 0$$

$$\sum_{t=t_k}^{t_k+h} \sum_i \sum_j s_{ij}^t \geq S \text{ ,} \quad \forall 0 \leq k \leq \bar{k} \text{ ,} \quad \bar{h} > h > 0 \text{ .}$$

It seeks to minimize the sum of initial balances in the special accounts (b_i), under the constraints that the set of payments that day is fixed and given by P_{ij}, that the balances are non-negative, and that the settlement under the new BOJ-NET special account procedures over a given time interval during the processing day (by value) are at least as high as some rate of settlement S, where S is some yen-rate of settlement per h minutes of the day (which we take as the time from the opening of the system to 16:00).

The problem outlined above is not fully specified, as it does not contain the full richness and complexity of the settlement algorithm used by the new BOJ-NET. Nonetheless, an examination of the problem clarifies the heuristic strategy we employ in seeking efficient levels of initial funding of the special accounts. First, notice that the rate of settlement is specified as the sum of all payments settled. The goal then is not to increase a particular participant's rate of settlement, but to increase the rate of settlement for the whole system. Second, the problem seeks to minimize the sum of initial balances, not any particular participant's initial balance.

By examining the structure of the problem outlined above, we can infer that the optimal levels of initial balances satisfy the following equalization-of-marginal- benefit condition. An extra yen added to any participant's initial balance has the same incremental effect on total settlements as an extra yen added to any other participant's initial balance. We can infer this because the variables of the balances enter the objective function in an additively separable way, so there cannot be any way, at the optimal level of balances, to shift balances among accounts (holding fixed the sum of balances) and increase the rate of settlement (otherwise we could reduce the sum of balances from the minimum level, which contradicts that the level is at a minimum). From that it must then be the case that an extra yen of initial balances increases the rate of settlement by the same amount regardless of into whose account that yen is added.

We rely on that feature of the optimal levels of initial balances to guide our heuristic strategy to characterize efficient levels of initial balances. We set $h = 420$, the time period over which settlement is measured, to be the period from the opening of the processing day until 16:00. We simulate the working of the system starting with various levels of initial balances (basic simulations). After each simulation we examine the performance of the system in terms of the value of the payments settled prior to 16:00, the value of the remaining unsettled payments at that time, the value of the additional amounts that need to be paid in to settle all the remaining unsettled payments, and the value-weighted average time of settlement. We examine the effects of the alternative levels of balance on the system as a whole, and, separately, for the "five mega-banks" and all the other participants (distributional simulations). We also examine the effects of the additional intraday funding besides the initial funding and the funding for the remaining unsettled payments at 16:00 (progress-payment approximation simulations). The results of these simulations give participants and planners a sense of how alternative levels of initial balances would affect the system's performance.

4. Simulations and results

4.1 Four basic simulations

We perform our simulations using ten days of historical data in September 2003. We conduct two sets of baseline simulations. Our first simulation is to simulate the performance of the current systems: the BOJ-NET, the FXYCS, and the large-value payments in the Zengin System, as they operate now. The simulation endows the participants with sufficient liquidity to settle their payments without delay (although it treats the FXYCS and the Zengin System as DNS systems), and uses the historical time of entry of the payments. As a result, these simulations provide a measure of current liquidity usage in the systems. We refer to these simulations as our *current baseline* simulations.

Another baseline simulation we perform is to endow the participants with the exact amount of funds (in the special account) that is equal to that day's multilateral net debit for each participant, given that day's payments history. A participant's multilateral net debit is the amount it would owe to settle its payments were the system a net settlement system. In general, the participants will not know their multilateral net debit in advance. This simulation can be thought of approximating the case in which the participants make pay-ins throughout the day as they gradually learn the size of their multilateral net debit. The hourly multilateral offsetting operations are one way the participants do learn the amount of their multilateral net debit. This simulation roughly approximates the learning process by assuming that they know the amount with certainty in advance. By endowing the participants with the exact amount of their multilateral net debit all payments are settled by 16:30, with no payments remaining after the closing time. We refer to these simulations as our *exact multilateral net debit (MND) funding* simulations or *progress-payment approximation* simulations.

Our third basic simulation endows the participants with their average multilateral net debit funding, where the average is taken over the ten days of the sample period. These simulations are first to assume that the participants fund their special accounts in the morning and then make another pay-in to the special accounts after 16:00 to settle the payments that remain unsettled at that time. The average multilateral net debit is, of course, quite close in size to the exact multilateral net debit amounts used in the *exact MND funding* simulations. However, because it is an average, some payments will remain unsettled at 16:00. We refer to these simulations as the *average MND funding* simulations.

Our fourth basic simulation endows the participants with half the amount of funding as in the average MND funding simulations. We refer to these simulations as the *half average MND funding* simulations.

Figures 1, 2, and 3 below show the performance of these four simulations on average across the ten days of the sample period with regard to the amounts of the initial balance used in the simulations, the cumulative amount settled by 16:00 (and, therefore, the amounts left to be settled), and the value-weighted average time of settlement. Table 1 provides that information and also displays the additional amounts of pay-ins to the special accounts that would be required after 16:00 to settle those payments that still remain at that time. An average time of settlement of 180 corresponds to settlement at noon, as the minutes measure the time since the opening of the system at 9:00. Because the analysis of only ten days yields a small sample, we do not consider the statistical significance, but simply examine averages.

Table 1: Averages from the basic simulations

Source: Authors' calculation.

Note: Figures in brackets are ratios of each item to that of the current baseline simulations.

JPY billion; minutes

	Initial balances	Megas' initial balances	End-of-day pay-ins	Cumulative value settled at 16:00	Gross value unsettled at 16:00	Average time of settlement
Current baseline	13,780 (-)	3,460 (-)	0 (-)	56,673 (-)	12,625 (-)	251 (-)
Exact MND	3,975 (0.288)	492 (0.142)	0 (-)	61,106 (1.078)	8,192 (0.649)	202 (0.806)
Average MND	3,964 (0.288)	492 (0.142)	3,224 (-)	55,954 (0.987)	13,344 (1.057)	213 (0.851)
Half average MND	1,982 (0.144)	246 (0.071)	3,712 (-)	48,119 (0.849)	21,180 (1.678)	249 (0.991)

Figure 1 shows the total value settled by 16:00 in the average of the simulations for the various scenarios together with the initial balances in each case. The *exact MND funding* simulation clearly settles more payments by that time of the day with the initial balances as small as one-third of those the *current baseline* simulations require. The *average MND funding* simulations also have the same qualitative results relative to the *current baseline* simulations, using fewer initial balances than the *current baseline* simulations. The amount settled by 16:00 in the *half average MND funding* simulations is far less than that in the three other scenarios, though economizing too much of the initial balances.

Figure 1: The total value settled by 16:00 and the amount of the initial balances used

Source: Authors' calculation.

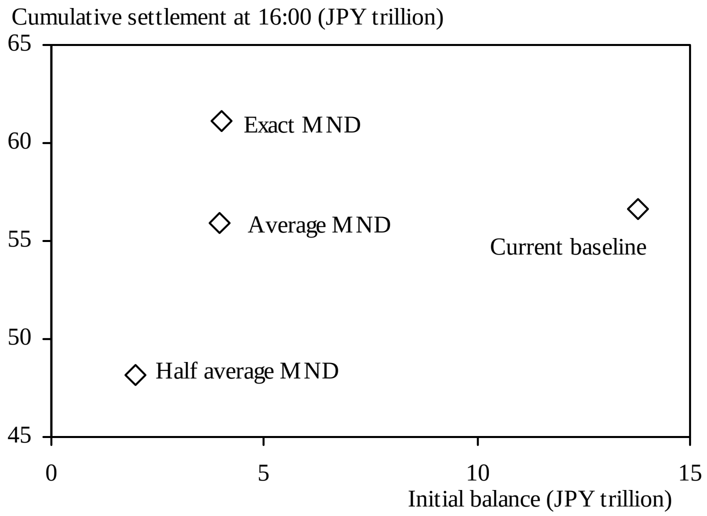


Figure 2: The value-weighted average time of settlement and the total liquidity required

Source: Authors' calculation.

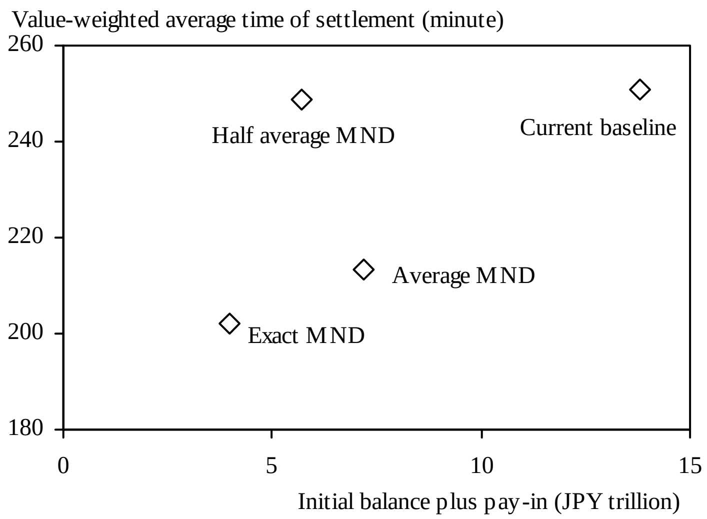


Figure 2 shows the value-weighted average time of settlement and the total liquidity required in the simulations, both the initial balance and the pay-in required to settle all payments after 16:00. Here again, we see that the *average MND funding* simulations, and the *exact MND funding* simulations perform quite similarly. Although the *half average MND funding* simulations settle on average only slightly quicker than the *current baseline* simulations, it uses much less liquidity than the *current baseline* simulations. Because of its larger pay-in after 16:00, the *half average MND funding* simulations use almost as much liquidity in total as the *average MND funding* simulations.

Figure 3: The value-weighted average time of settlement and the total value settled by 16:00

Source: Authors' calculation.

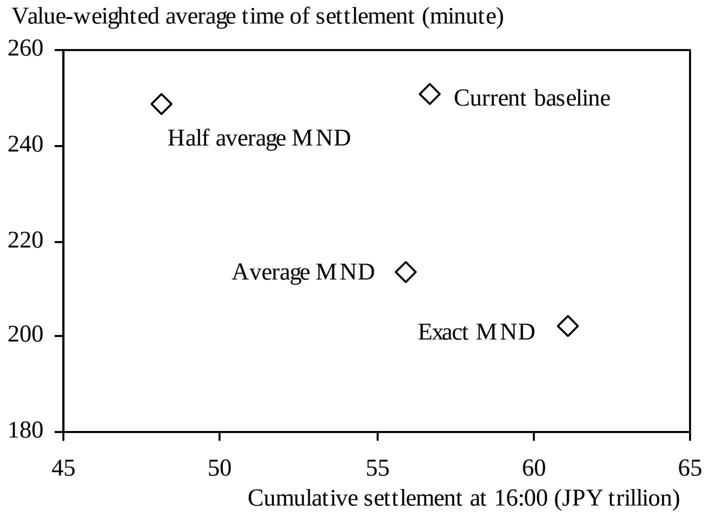


Figure 3 shows the value-weighted average time of settlement and the cumulative settlement by 16:00 for the various cases. The settlement performance gets better off as the outcome plotted on the chart moves toward the bottom right, and *vice versa*. From the viewpoint of quickness of settlement the four scenarios can be roughly arranged in the desirable order as the *exact MND funding*, the *average MND funding*, the *current baseline*, and the *half average MND funding*.

These results show that even with the *average MND funding* levels, which are less than half the liquidity used in the *current baseline* simulations, payments would settle more quickly in new BOJ-NET than they currently do. This reflects, in part, the current DNS method of FXYCS and the Zengin System. Those settlements will be made more quickly using the procedures available in the new BOJ-NET, so long as sufficient funding is available in the special accounts. Furthermore, the *average MND funding* simulations result in about 20 percent of payments unsettled at 16:00. These payments would be settled with an additional pay-in of 3.2 trillion yen, so that total liquidity used in these simulations is about twice as high as in the *exact MND funding* simulations. Overall, the *exact MND funding* simulation settles payments most quickly, and uses less liquidity than the *average MND funding* simulation. This suggests that were banks to make pay-ins during the day in line with their multilateral net debits following the hourly net settlements, they might be able to have fewer payments unsettled after 16:00.

In comparing the performance of the *average MND funding* simulations and the *half average MND* simulations, the latter settles fewer payments by 16:00, and has a later average time of settlement (although it too settles payments a bit more quickly than the current system on average). It has approximately 30 percent of the payments unsettled at 16:00. To settle these payments requires a pay-in of 3.7 trillion yen. Overall, the *half average MND* simulation uses about 80 percent of the liquidity used in the *average MND funding* simulation, after taking into account the large pay-in at the end of the day. This result reminds one that as one limits the amount of liquidity available to the system initially, larger pay-ins would be required later in the day.

The results of our basic simulations suggest that the new BOJ-NET may perform quite satisfactorily with levels of liquidity that are significantly lower than those currently used in the settlement of the systems. In addition, the behavior of our rough approximation to progress payments suggests that the participants may be better able to conserve on funding by making pay-ins to the system during the day, as they learn the debit associated with that day's payments.

4.2 Distributional funding simulations

In addition to the basic simulations, we perform some additional simulations that show the effects of small changes in the funding provided by the five largest participants (referred as "mega banks"). These simulations are conducted with the other participants in the system being endowed first with the exact multilateral net debit funding, for the second set of these simulations with the average of that level of funding, and the final set with half of the second set. Because those participants are exactly endowed with their multilateral net debit amounts, the first set of these simulations are probably best compared with the *exact MND funding* simulation. The amounts that the five largest participants are endowed with are quite small amounts equal to the 90th percentile of the size of the payments they each send and receive on the current BOJ-NET alone (this amount is equal to 3.5 JPY billion, and is a bit larger than the 90th percentile of the size of their payments on the three current systems). So these simulations are indicative of a situation in which all but the five largest participants make regular progress-payments in the amounts of their multilateral net debits, and the five largest participants supply very little in the initial funding amounts. These simulations are not meant to model the behavior of participants, but rather to investigate the behavior of the new BOJ-NET as we vary the funding of the participants in different ways.

These simulations are illustrative of the effects of small changes in particular participants' funding levels. To investigate these effects for individual participants would be quite time consuming and require many simulations. Because of those resource requirements, we forego such an investigation in this paper.

The first set of simulations shows that reducing the five largest participants' total funding from 492 JPY billion as in the *exact MND funding* simulation, to 18 does not substantially reduce the speed of settlement (see Table 2), with the value-weighted average time of settlement changing from 202 minutes to 214. Nor is the total amount settled by 16:00 reduced appreciably, even though the largest five participants had multilateral net debits of approximately 500 JPY billion on the sample days. These results show that individual participants, or even groups of participants, can significantly reduce their initial level of funding without necessarily causing proportional changes in the amounts settled. Further research could determine the local optimum in the funding amounts.

Table 2: Averages from the exact MND funding simulations with the 90th percentile funding

Source: Authors' calculation.

Note: Figures in brackets are ratios of each item to that of the exact MND funding simulations.

JPY billion; minutes

	Initial balances	Megas' initial balances	End-of-day pay-ins	Cumulative value settled at 16:00	Gross value unsettled at 16:00	Average time of settlement
Exact MND	3,975 (-)	492 (-)	0 (-)	61,106 (-)	8,192 (-)	202 (-)
+90 percentile	3,500 (0.881)	18 (0.036)	1,527 (-)	58,170 (0.952)	11,129 (1.359)	214 (1.060)
+90 percentile*2	3,518 (0.885)	35 (0.071)	1,452 (-)	58,495 (0.957)	10,803 (1.319)	214 (1.061)
+90 percentile*3	3,535 (0.889)	53 (0.107)	1,405 (-)	59,025 (0.966)	10,274 (1.254)	213 (1.053)

The second set of simulations endowed all but the largest five participants with their average multilateral net debit amounts, as in the *average MND funding* simulations (see Table 3). In this simulation, which is best compared with the *average MND funding* simulations, again, we see that the performance of the system remains quite good even though the largest five participants' funding levels are reduced substantially. The amounts settled by 16:00 falls by only 3 percent. The value-weighted average time of settlement occurs 12 minutes later.

Table 3: Averages from the average MND funding simulations with the 90th percentile funding

Source: Authors' calculation.

Note: Figures in brackets are ratios of each item to that of the average MND funding simulations.

JPY billion; minutes

	Initial balances	Megas' initial balances	End-of-day pay-ins	Cumulative value settled at 16:00	Gross value unsettled at 16:00	Average time of settlement
Average MND	3,964 (-)	492 (-)	3,224 (-)	55,954 (-)	13,344 (-)	213 (-)
+90 percentile	3,490 (0.880)	18 (0.036)	3,398 (1.054)	54,172 (0.968)	15,128 (1.134)	223 (1.044)
+90 percentile*2	3,507 (0.885)	35 (0.071)	3,371 (1.046)	54,056 (0.966)	15,243 (1.142)	222 (1.042)
+90 percentile*3	3,525 (0.889)	53 (0.107)	3,366 (1.044)	54,621 (0.976)	14,678 (1.100)	221 (1.033)

The final set of these simulations, in which the participants other than the largest five have their initial funding levels set at half of the average multilateral net debit, confirms the result that reducing the funding levels of the largest five participants quite dramatically does not reduce settlements by that proportion (see Table 4).

Table 4: Averages from the half average MND funding simulations with the 90th percentile funding

Source: Authors' calculation.

Note: Figures in brackets are ratios of each item to that of the half average MND funding simulations.

JPY billion; minutes

	Initial balances	Megas' initial balances	End-of-day pay-ins	Cumulative value settled at 16:00	Gross value unsettled at 16:00	Average time of settlement
Half average MND	1,982 (-)	246 (-)	3,712 (-)	48,119 (-)	21,180 (-)	249 (-)
+90 percentile	1,754 (0.885)	18 (0.071)	3,756 (1.012)	46,017 (0.956)	23,282 (1.099)	259 (1.041)
+90 percentile*2	1,772 (0.894)	35 (0.142)	3,724 (1.003)	46,350 (0.963)	22,948 (1.083)	258 (1.037)
+90 percentile*3	1,789 (0.902)	53 (0.214)	3,720 (1.002)	46,494 (0.966)	22,804 (1.077)	257 (1.033)

In each set of the simulations just discussed, we vary the funding levels of the largest five participants by endowing them with multiples of 18 JPY billion, namely 35 and 53 for their initial balance. These increases in the levels of initial balances do not appreciably change the outcome. In general, the outcome tends to be a greater amount settled with additions to the initial funding levels of the largest five participants, but this is not always true. In fact, raising the largest five participants' initial funding from 18 JPY billion to 35 reduces the amounts settled by 16:00 in the second set of simulations. This implies that the amount settled by 16:00 is not a monotone increasing function of some particular participants' initial balances. It is necessary to consider not only the total balance of the participants but also the distribution of that balance among the participants when we discuss efficiency of settlement.

4.3 Progress-payment approximation simulations

We develop the *exact MND funding* simulations to approximate to the more rigid *progress-payment approximation* simulations. In so doing, we relax the severe assumption, which is contrary to the design of the new BOJ-NET, that the participants can fund their special accounts only at the opening of the processing day and for settlement of their unsettled queued payment instructions at 16:00. Instead, add the new assumption that the participants can put additional funds in their special accounts once during the day in addition to the start and end of the day funding, though we continue not to allow the participants to withdraw funds from the special accounts. In these simulations the participants start the day with the half average amounts of multilateral net debit as in the *half average MND funding* simulations. At a particular time during the day other than the end-of-day, for example at 10:00 or 12:00, all participants add full or half multilateral net debit of payments unsettled at that time. These simulations are best compared with the *half average MND funding* simulations, and approximate the learning process well by assuming that they learn their multilateral net debit amounts with certainty at those times.

Table 5: Averages from the progress-payment approximation simulations

Source: Authors' calculation.

Note: Figures in brackets are ratios of each item to that of the half average MND funding simulations.

JPY billion; minutes

	Initial balances	Intraday pay-ins	End-of-day pay-ins	Cumulative value settled at 16:00	Gross value unsettled at 16:00	Average time of settlement
Half average MND	1,982 (-)	0 (-)	3,712 (-)	48,119 (-)	21,180 (-)	249 (-)
+Exact MND at 10:00	1,982 (1.000)	6,095 (-)	2,780 (0.749)	61,621 (1.281)	7,678 (0.362)	171 (0.690)
+Half exact MND at 10:00	1,982 (1.000)	3,047 (-)	3,202 (0.862)	59,152 (1.229)	10,146 (0.479)	195 (0.786)
+Exact MND at 12:00	1,982 (1.000)	5,571 (-)	2,302 (0.620)	62,681 (1.303)	6,617 (0.312)	190 (0.764)
+Half exact MND at 12:00	1,982 (1.000)	2,785 (-)	3,094 (0.834)	59,076 (1.228)	10,223 (0.483)	210 (0.844)

Table 5 shows that the intraday pay-ins dramatically improve the performance of settlement in terms of both settlement speed and value. The value-weighted average time of settlement goes down from 249 minutes to 170-210, and the total amount settled by 16:00 increases by 20-30 %. This performance corresponds to that of the *exact MND funding* simulations. In return for the high performance, the participants have to make a large amount of the intraday pay-ins, which is over 1.4-3.0 times as much as the initial funding level of the *half average MND funding* simulations. As a result, the total balances required to settle all payments of that day are larger than all but the *current baseline* simulations. We can see a clear trade-off between the funding levels and the settlement performance. The results imply that this type of funding scenarios attempts the improvement of the settlement performance at the expense of the efficient distribution of funding.

Further findings are that the larger intraday pay-ins leads to the further improvement of the settlement performance in terms of both settlement value and speed, and that the earlier the timing of the intraday pay-ins, the greater the settlement performance improves. The former finding can be easily guessed based on the simple rule that the more funding the more settlement. The latter finding comes from a unique submission pattern of payment instructions. Most payment instructions are submitted early in the morning, so more than 40 % of instructions are submitted until 10:00 on a transaction basis, and 80 % until 12:00.

5. Liquidity effects of combining the FXYCS, the Zengin System, and the BOJ-NET payments

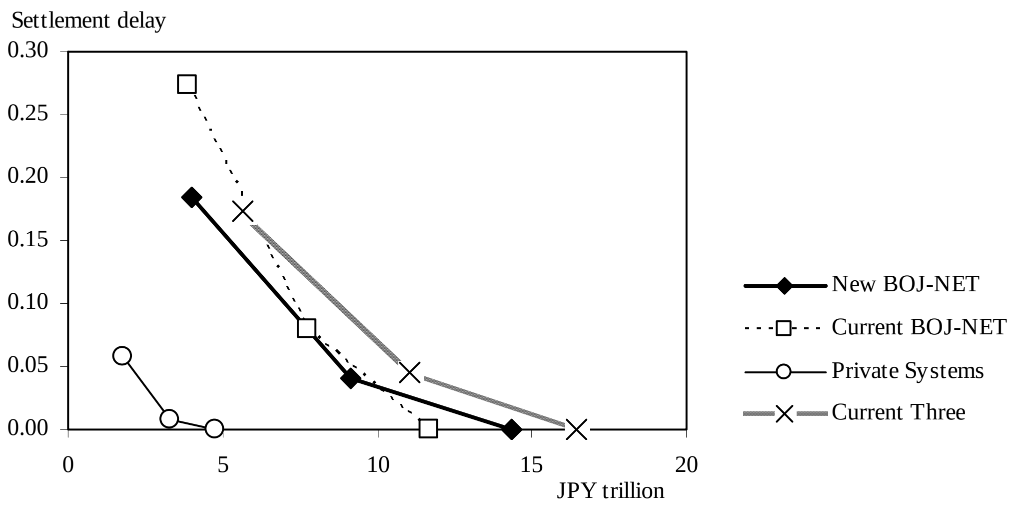
As we have described, the new BOJ-NET plans to incorporate payments currently made on the BOJ-NET, the FXYCS, and the large-value payments on the Zengin System. Will the combination of these systems increase liquidity efficiency by aggregating currently fragmented payment systems, or will it reduce it by eliminating DNS systems (but with the obvious benefit of permitting intraday settlement of payments)? We examine this question by first simulating the operation of the new BOJ-NET with payments that are currently settled in the BOJ-NET. Then we conduct simulations of the performance of the FXYCS and the large-value payments on the Zengin System, as though they are separately operated (but using the settlement method of new BOJ-NET). Adding the liquidity used in these two simulations provides an indication of the liquidity that would be used in the Japanese payment systems were the BOJ-NET, the FXYCS and the Zengin System to remain separate systems, but all adopt an intraday finality capability. Finally, we simulate the performance of the new BOJ-NET when payments from all three systems are combined and settled in the same system. If the liquidity required to settle the combined payments is lower than that required to settle the payments when the systems are operated separately (for a fixed level of delay) then we can expect that there are liquidity complementarities, or scale economies in liquidity use, in combining the systems. If, on the other hand, liquidity use is less with the systems operated separately, then there are diseconomies in liquidity use in combining the systems.

For each payment system, we conduct three treatments on each day's data (we use the ten days of historical data in the simulations that we report on here). The first treatment is to endow the participants with sufficient liquidity to settle the day's payments without delay. The second is to settle the payments as quickly as possible (using the new BOJ-NET settlement algorithm) when the participants are endowed with sufficient liquidity only to settle their multilateral net debit. Finally, in the third treatment, we endow the participants with the average of the two other levels of liquidity – in other words, we endow them with liquidity that is halfway between the level sufficient to settle payments without delay and the level of the multilateral net debit.

We examine the trade-off between the liquidity necessary to settle the payments, and the delay with which the payments are settled. If the locus of points that describe this trade-off shifts inward or outward as the different payment streams are added, we can say that there are definite liquidity efficiencies or costs to combining the different payment streams.

Figure 4: Delay indicator and liquidity for the separate systems, the sum of the separate systems operating in isolation, and for the combined system, all using the settlement method of the new BOJ-NET

Source: Authors' calculation.



The results of these simulations, using the ten days of historical payment data, are shown in Figure 4. In general we find that there are significant liquidity complementarities in combining the systems. This can be seen clearly in the inward shift of the black line (the new BOJ-NET), which illustrates the performance of the combined systems, relative to the gray line (the current three systems), which illustrates the total liquidity requirements of the systems when operated separately. The inward shifts show that at the three levels of delay we simulate, the combined system requires less liquidity to settle the same payments.

Table 6 provides more detail on the average of the ten days of simulated data, and presents both the delay indicator measure (the details of its specific definition are presented in Appendix A.4) and the value-weighted average time of settlement. In every simulation, and for any average time of settlement or any indicator of delay of settlement, the combined system requires less liquidity to settle the payments. Our results therefore suggest that there are significant liquidity complementarities, or economies of scale in liquidity use associated with the combination of the payment streams from the three systems. On average, across the treatments and the days, combining the systems results in a 20 percent reduction in liquidity use.

Table 6: Liquidity use, delay indicator, and value-weighted average time of settlement for the separate systems and for the combined system

Source: Authors' calculation.

Notes: Level (1) endows the participants with sufficient liquidity only to settle their multilateral net debit, Level (2) with liquidity that is halfway between the level sufficient to settle payments without delay and the level of the multilateral net debit, and Level (3) with sufficient liquidity to settle payments without delay.

JPY billion; minutes

			Level (1)	Level (2)	Level (3)
New BOJ-NET					
		Liquidity	3,975	9,159	14,344
		Delay	0.185	0.041	0.000
		Time	202	158	146
Current Three Systems					
		Liquidity	5,649	11,032	16,415
		Delay	0.173	0.042	0.000
		Time	197	159	146
	Current BOJ-NET				
		Liquidity	3,850	7,760	11,670
		Delay	0.274	0.080	0.000
		Time	236	178	154
	Private Systems				
		Liquidity	1,799	3,272	4,745
		Delay	0.058	0.007	0.000
		Time	154	138	136

It is an interesting feature of the system that the current BOJ-NET requires less liquidity than the combined system (the new BOJ-NET) to process its payments without delay, but requires more liquidity than the combined system to settle its payments on a multilateral net basis. This suggests that as some of the FXYCS and the large-value Zengin System payments arrive later in the day, they offset with some current BOJ-NET payments that arrive earlier in the day. As the BOJ-NET payments are delayed a bit, they settle with less liquidity when combined with payments from the other two systems. Again, this indicates particularly strong liquidity complementarities among the systems. It should also be noted that while the combined system settles without delay using more liquidity, a close examination of Table 6 shows that the combined systems settled at an earlier hour of the day than the current BOJ-NET, when the participants are endowed with sufficient liquidity to settle payments without delay.

6. Concluding remarks

In our paper, to investigate how the levels of the initial balances change the speed and value of settlement, we simulate three sets of scenarios: the basic simulation, the distributional funding simulation, and the progress-payment simulation.

The basic simulation shows that the *exact MND funding* is the most efficient among scenarios of the basic simulations in the sense that the *exact MND funding* settles payments most quickly, and uses less liquidity than any other funding levels. The distributional funding simulation is illustrative of the effects of small changes in particular participants' funding levels. The results tell that injecting the lower levels of the initial liquidity to the particular participants' accounts do not substantially affect the settlement speed, and that the small increase of initial liquidity of these participants does not result in improving the performance of settlement. We also find that, conducting the *progress-payment approximation* simulation, the more quickly the additional pay-ins are put in, the more quickly payments progress.

In addition to the three set of scenarios, we conduct another simulation and compare the single large-value payment system (the new BOJ-NET) with the dual large-value payment systems (coexistence with the current BOJ-NET and the two private systems). The results show that there are strong scale economies in liquidity use, and that there are definite liquidity efficiencies or cost efficiencies in combining the different payment streams.

It is difficult to describe the initial funding optimization problem under the queue-augmented RTGS with queuing and offsetting mechanisms, and to reach the local optimum solution. This is because there is no intraday rate of interest that is easily observable, and because it does not contain full richness and complexity of the settlement algorithm of the new BOJ-NET. It would be, however, useful to attempt to seek the desirable solution conducting the simulation analysis in the heuristic way. As we mention above, the progress rate of intraday settlement is not a simple monotone increasing function of the initial funding level. To approach the best solution, it is necessary to care about not only the absolute level of the total balance but also the distribution of the funding levels across the participants. Taking this problem forward would require many simulations developing possible scenario and many trials to approach the realistic funding pattern. This work, which is supposed to be quite time consuming, would be useful to encourage the participants to establish new market practices for the funding of the special accounts in the new BOJ-NET, as that may promote both a smooth transition to the new system, and satisfactory settlement patterns for the participants.

Appendix

A.1 Simulator

We use the BOJ-NET simulator developed by the Yajima Laboratory of the Tokyo Institute of Technology, whose research interests are focused on mathematical programming and operations research. Its basic functions are almost the same as those of the Bank of Finland Payment and Settlement Simulator (BoF-PSS2).[5] Highly complicated offsetting algorithms with settlement-value maximization or time-weighted settlement-value maximization modes are available on the BOJ-NET simulator as well as the standard offsetting algorithms based on FIFO or bypass FIFO rules, which are described below.

A.2 Simulation data

The simulations are performed using actual data of ten consecutive business days (16, 17, 18, 19, 22, 24, 25, 26, 29, and 30 in September 2003). The data includes: the money-market transactions excluding those with the Bank of Japan; the foreign exchange yen transactions, those of which are handled on both a net settlement and a gross settlement modes; and the large-value customer transactions, those of which are

[5] See Leinonen and Soramäki [2003] for the BoF-PSS2.

100 million yen and over per transaction. See Table 7 for those basic statistics.

Table 7: Basic statistics on the simulation data

Source: Authors' calculation based on data from the Japan Bankers Association and the Bank of Japan.

JPY billion

		Average daily volume	Average daily value	Average value	S.D. of value
Total transactions		61,709	69,979	1.134	7.851
	MM transactions	7,558	37,487	4.960	20.134
	FXY transactions	40,368	23,010	0.570	3.801
	LV customer transactions	13,783	9,483	0.688	1.483

A.3 Bilateral and multilateral offsetting algorithms

We use two types of offsetting algorithms to perform the simulations: the multilateral offsetting and the bilateral offsetting.

The multilateral offsetting algorithm runs once every hour, for example, 10:00, 11:00, 12:00, 13:00, 14:00, 15:00, 16:00, and the end-of-the-day (16:30). The multilateral offsetting algorithm attempts to find the large set of queued payments that can be settled using available balances, and successively drops the latest submitted payments from the participant with the largest funding shortfall until a set of payments that have no funding shortfalls is found.

The bilateral offsetting algorithm (including single-gross settlement) initiates when one of the following events occur, and attempts to simultaneously settle a pair of payments on a bypass-FIFO basis: 1) increase in the balance; 2) submission of the new payment instruction; and 3) settlement or reorder of the top of queued payments.

A.4 Analytical framework

We calculate the settlement delay as the time difference between the payment submission to the system and the payment finality that implies that the payment is irrevocable and unconditional. The two statistics that we use to measure the settlement delay are the value-weighted average time of settlement and the delay indicator.

The value-weighted average time of settlement (VWATS), which is the average time weighted by the value of the payments settled at each minute, is defined as follows:

$$VWATS = \frac{\sum_i t_i \times v_i}{\sum_i v_i},$$

where t_i and v_i represent respectively the settlement time and the value of the payment i. If all payments are settled at the opening of the day (9:00), then VAWTS has the value zero minute. If no payments are settled during the day, and if all payments are settled at the end of the day (16:30), then VWATS takes the value of 450 minutes.

The delay indicator (DI) is defined as follows:

$$DI = \frac{\sum_i (t_{2,i} - t_{1,i}) v_i}{\sum_i (t_{end} - t_{1,i}) v_i},$$

where $t_{1,i}$ and $t_{2,i}$ are respectively the submission time and the settlement time of the payment i; and t_{end} is the time for the end of the business day (16:30). DI runs from zero (no delay for the system) through one (no settlement during the day). See Bech and Soramäki [2001] for further discussions of DI.

References

Angelini, P. [1998] "An Analysis of Competitive Externalities in Gross Settlement Systems," Journal of Banking and Finance 22.

Bank for International Settlements [1997] "Real-Time Gross Settlement Systems," Committee on Payment and Settlement Systems Publications.

Bank for International Settlements [2003] "Payment and Settlement Systems in Selected Countries," Committee on Payment and Settlement Systems Publications.

Bank for International Settlements [2005] "New Developments in Large-Value Payment Systems," Committee on Payment and Settlement Systems Publications.

Bech, M., and K. Soramäki [2001] "Gridlock Resolution in Interbank Payment Systems," Bank of Finland Discussion Papers, No. 9.

Bech, M., and R. Garratt [2003] "The Intraday Liquidity Management Game," Journal of Economic Theory 109.

Imakubo, K. [2005] “Settlement Modes and Participants’ behaviors,” Bank of Japan Working Paper Series, forthcoming.

Johnson, K., J. McAndrews, and K. Soramäki [2004] “Economizing on Liquidity with Deferred Settlement Mechanisms,” Federal Reserve Bank of New York Economic Policy Review.

Leinonen, H., and K. Soramäki [1999] “Optimizing Liquidity Usage and Settlement Speed in Payment Systems,” Bank of Finland Discussion Papers, No. 16.

McAndrews, J., and J. Trundle [2001] “New Payment System Designs: Causes and Consequences,” Financial Stability Review, Bank of England.

Roberds, W. [1999] “The Incentive Effects of Settlement Systems: a Comparison of Gross Settlement, Net Settlement, and Gross Settlement with Queuing,” IMES Discussion Paper Series 99-E-25, Bank of Japan.