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Funding Levels for the New Accounts in the BOJ-NET

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Abstract

The Bank of Japan decided to implement the next-generation RTGS project of the BOJ-NET Funds Transfer System. Under the project, the new system will have liquidity-saving features and will incorporate large-value payments that are currently handled by two private-sector designated-time net settlement systems, the Foreign Exchange Yen Clearing System and the Zengin System. We analyze characteristics of the optimal funding levels under the new features using simulation analysis. We find that the optimal funding levels can be described with the total balances in the system, the distribution of the total balances across participants, and the timing of funding.

Keywords: queue-augmented RTGS, simulation analysis, economies of scale, optimization problem.

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1. Introduction

In February 2006, the Bank of Japan decided to implement the next-generation RTGS (RTGS-XG) project of the BOJ-NET Funds Transfer System (BOJ-NET), its primary large-value payment system.[1] Under the RTGS-XG project, BOJ-NET will introduce liquidity-saving features in a current real-time gross settlement (RTGS) mode. The new system will also incorporate payments from three different streams of the current payment activities, two of which now settle toward the end of the processing day in private-sector designated-time net settlement (DNS) systems. The project will be implemented in two phases, with the first phase scheduled for fiscal 2008 (April 2008 - March 2009) and the second for 2011. One of the primary motivations for the development of the new system is to quicken settlement of large-value payments relative to the current pattern, and to reduce intraday settlement exposure of those payments, by allowing for intraday settlement finality and liquidity-saving at the same time.

Much of the design work for the new system is already completed, while some decisions related to the implementation still remain. In the paper, we focus on one aspect of the new system, the levels of funding for newly developed accounts that will be drawn on to effect settlement throughout the day in a liquidity-saving mode.

The first issue that we explore is whether the plan to incorporate the payments that are currently settled on the two private-sector DNS systems and most payments on the current BOJ-NET into the new system will yield liquidity-saving under a certain level of funding. 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 incorporating the payments in the three systems turns to be liquidity-saving, then it can be said that there are liquidity complementarities among the three systems to be combined. As demonstrated in the paper, strong complementarities do exist among the three systems.

[1] See Bank of Japan [2006] for an overview of the RTGS-XG project.

Second, we simulate the performance of the new system using several levels of initial balances for the new accounts. In general, there is a clear trade-off between the rate of settlement of a group of payments and the level of funding devoted to those settlement. With a large level of funding, settlement can be made more quickly. First then, the total 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 total 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 allocation problems in economics.

We examine how changes in a level of initial balances affect the value of payments settled, the amounts left unsettled after a particular time, 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 system. In the context of Japan's payment activities, this is the first examination studying effects of liquidity on intraday settlement.

The 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 system is expected to alter that landscape. We also provide a rough description of the planned new system and explain the purpose of the new account and its funding. In Section 3 we examine changes in liquidity efficiency of combining the two new payment streams with the payments on the current BOJ-NET. In Section 4 we describe the problem of finding optimum funding levels, and in Section 5 we present the results of simulation analysis. In Section 6 we provide a short summary and conclusion.

2. Large-value payments in Japan

Current structure of large-value payment systems

BOJ-NET plans to incorporate payments currently made on BOJ-NET, the Foreign Exchange Yen Clearing System (FXYCS), and the large-value payments on the Zengin Data Telecommunication System (Zengin). We briefly describe some aspects of these three systems.[2]

BOJ-NET is a pure RTGS system for the Japanese yen, owned and operated by the Bank of Japan. The system is one of the core financial infrastructures supporting economic and financial activities in Japan. It settles almost 100 trillion yen daily with annual turnover ranging 40 times as high as Japan's nominal GDP.

BOJ-NET handles both Japanese government Securities (JGSs) and funds transfers. The latter mainly consist of money-market transactions, but also include the settlement payments for various payment and securities settlement systems that use BOJ-NET to transfer the final settlement payments and the cash legs. In addition, money-market operations of the Bank of Japan are carried out using BOJ-NET. There are a limited number of third-party, or customer, payments settled on BOJ-NET, and those are very high value payments, indicating that these are also money-market transactions conducted by market participants that do not have accounts with the Bank of Japan. Settlement amounts in 2005 indicated that on a daily average basis BOJ-NET settled 21,641 transfers with a total value of JPY 88.3 trillion. The average value per settlement was JPY 4.1 billion.

FXYCS is basically a DNS system that handles yen legs of foreign exchange trades. It conducts the final settlement at 14:30 using BOJ-NET. The volume and value of its daily average activities in 2005 indicated that it settled 28,022 transactions per day with a total value of JPY 16.4 trillion. The average value per transaction was JPY 586 million. The net amount transferred on BOJ-NET in 2005 averaged JPY 4.1 trillion.

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[2] For an overview of payment systems in Japan, see the Japan section of Bank for International Settlements [2003].

FXYCS has not only a DNS mode but also an RTGS mode, although its use is rather limited.

Finally, Zengin is a simple DNS system, whose final payment takes place at 16:15. In 2005, Zengin averaged 5.4 million transactions per day with a total daily average value of JPY 9.5 trillion. The average size of payments was JPY 1.8 million. It is mainly used for commercial payments. On average, the daily settlement amounts made through BOJ-NET were JPY 1.8 trillion per day in 2005. It is estimated that roughly two-thirds of the value transferred on Zengin, approximately JPY 6 trillion per day, is made by payments that were larger than JPY 100 million.

Future structure of large-value payment systems

The new system plans to operate as a queue-augmented RTGS system.[3] The new liquidity-saving features will be provided on a new type of accounts as shown in the Table 1. Participants will be able to designate payment instructions to be settled either via the new accounts, that will not offer intraday overdrafts capability, or via the standard accounts, on which collateralized overdrafts will remain available. The intent of both participants and the Bank of Japan is that most of the three payment streams just described above will be settled via the new accounts. The standard accounts and the dedicated accounts for simultaneous processing of delivery-versus-payment and collateralization, known as SPDC, will still operate and be intended to be used for the rest of settlements.[4]

The new system will operate the new accounts as follows. The new accounts will be funded by participants each morning at the start of the processing day (9:00) with an infusion of funding from the standard accounts. That establishes the participants'

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[3] See BIS [1997], McAndrews & Trundle [2001], and BIS [2005] for basic ideas of a queue-augmented RTGS.

[4] The SPDC facility is another type of liquidity-saving facility used only for settlement of cash legs of JGSs transactions. It allows the receiver of JGSs to pledge the incoming securities as collateral for intraday overdrafts, while using the overdrafts to pay for the incoming securities. Similarly, the deliverer of JGSs is able to withdraw the securities pledged with the Bank of Japan for delivery to the receiver, while using the funds received to repay the overdrafts.

initial balances in the new accounts, because the new accounts will have a zero balance overnight. Participants will then submit payment instructions to the new accounts, and a bilateral offsetting algorithm will initiate a search for bilaterally offsetting payments on a FIFO basis. If a pair of bilaterally offsetting payments is found, and if funds are sufficient to settle the payments, settlement of the selected payments takes place simultaneously. At designated times, a multilateral offsetting algorithm will attempt to find the largest set of payments that can be settled using available balances.[5] See Appendix for the details of bilateral and multilateral offsetting algorithms in the new system.

Table 1 Account structure in the new system

	Standard account	SPDC account	New account
Types of transactions settled	- interbank transfers (e.g. money market, foreign exchange) - third-party transfers - the cash legs of securities transactions - settlement obligations arising from clearing systems - transactions with BOJ/ government	- the cash legs of JGSs transactions using the SPDC facility	- interbank transfers (e.g. money market, foreign exchange) - third-party transfers (including large-value Zengin payments)
Liquidity supply	Intraday overdrafts	Intraday overdrafts, liquidity transfers from standard account	Liquidity transfers from standard account
Liquidity saving	Not applicable (pure RTGS)	SPDC facility	Queuing and offsetting mechanisms
Account management	Overnight	Intraday (zero balance at the end of the processing day)	Intraday (zero balance at the end of the processing day)
Opening and closing times	9:00-17:00*	9:00-16:30	9:00-16:30

* Closing time is 19:00 for participants that have applied for access to extended hours.

Participants will be able to transfer funds between their new accounts and their standard accounts freely throughout the day. Payment instructions remaining in the queue will be rejected if insufficient funds are submitted to the new accounts by 16:30. The standard accounts will remain open until 17:00.

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

3. Liquidity effects of combining FXYCS, Zengin, and BOJ-NET payments

As described above, the new system plans to incorporate payments currently made on BOJ-NET and FXYCS, and the large-value payments on Zengin. The question is whether the combination of these payment streams increase liquidity efficiency by aggregating the currently fragmented payment systems, or reduce it by eliminating the DNS systems but with the obvious benefit of permitting intraday settlement of payments? We examine this question by first simulating operations of the new system with payments that are currently settled in BOJ-NET. Then we conduct simulations of the performance of FXYCS and the large-value Zengin, using the settlement method of the new system, while assuming (contrary to the planned design) that they were separately operated from BOJ-NET. Adding liquidity required in each of these two simulations provides an indication of liquidity that would be used if BOJ-NET, FXYCS, and Zengin would remain separate systems, but all adopt an intraday finality capability. Finally, we simulate the performance of the new system when payment streams from all these systems are combined and settled in the same system. If liquidity required to settle the combined payment streams is lower than that required to settle the payments when the systems are operated separately (for a fixed level of delay), then it can be expected that there are liquidity complementarities, or scale economies in liquidity use, in combining the payment streams. 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 system, we conduct three treatments on each day's data (the ten days of historical data in September 2003 are used in the simulations that we report on here).[6] The first treatment is to endow participants with sufficient liquidity to settle the day's payments without delay. The second is to endow them with sufficient liquidity only to settle their multilateral net debit, with which the payments will be settled as quickly as possible (using the new settlement method). Finally, in the third treatment, participants are endowed with the average of the two other levels of liquidity – in other

[6] See Appendix for the summary statistics of simulation data.

words, they are endowed with liquidity that is halfway between the level sufficient to settle payments without delay and the level of multilateral net debits.

We examine a trade-off between liquidity necessary to settle the payments and delay with which the payments are settled. If the locus of points that describes this trade-off shifts inward or outward as the different payment streams are added, it can be said that there are liquidity efficiencies or costs respectively in combining the different payment streams.

The results of these simulations, using the ten days of historical data and the settlement method of the new system, are shown in Figure 1. On average it is found that there are significant liquidity complementarities in combining the payment streams. This can be seen clearly in the inward shift of the black line (New system), which illustrates the performance of the new system, relative to the grey line (Current three), which illustrates the total liquidity requirements of the three systems when operated separately. The inward shifts show that at all the three levels of delay simulated, the new system requires less liquidity to settle the payments.

Figure 1 Delay indicator and liquidity for the separate systems, the sum of the separate systems operating in isolation, and for the new system

Source: Authors' calculation.

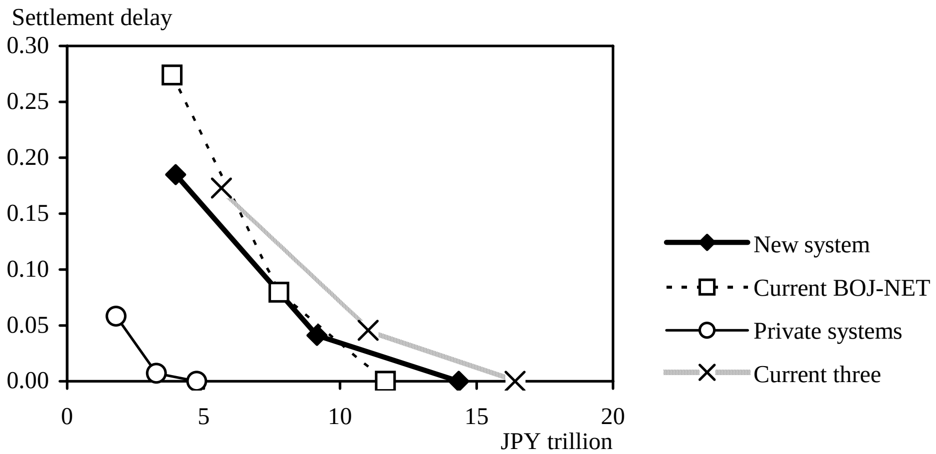


Table 2 provides more details on each of the ten days of simulated data, and presents both the delay indicator measure and the value-weighted average time of settlement.[7] In every simulation, and for any average time of settlement or any indicator of delay of settlement, the new system requires less liquidity to settle the payments. The 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 payment streams results in 20 percent reduction in liquidity use.

Table 2 Liquidity use, delay indicator, and value-weighted average time of settlement for the separate systems and for the new system

Source: Authors' calculation.

Note: Level (1) endows 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 debits, and Level (3) with sufficient liquidity to settle payments without delay.

JPY billion; hh:mm

	Level (1)	Level (2)	Level (3)
New system			
Liquidity	3,975	9,159	14,344
Delay	0.185	0.041	0.000
Average time	12:22	11:38	11:26
Current three systems			
Liquidity	5,649	11,032	16,415
Delay	0.173	0.042	0.000
Average time	12:17	11:39	11:26
Current BOJ-NET			
Liquidity	3,850	7,760	11,670
Delay	0.274	0.042	0.000
Average time	12:56	11:39	11:34
Two private systems			
Liquidity	1,799	3,272	4,745
Delay	0.058	0.007	0.000
Average time	11:34	11:18	11:16

It is an interesting feature of the system that the current BOJ-NET requires less liquidity than the new system to process its payments without delay, but requires almost the same level of liquidity as the new system to settle its payments on a multilateral net basis. This suggests that as some of FXYCS and large-value Zengin payments arrive later in the day, they offset with some current BOJ-NET payments that arrive earlier in the day but still remain in the queue. As the current BOJ-NET payments are settled with a

[7] Specific definitions of these indicators are described in Appendix.

slight delay, they settle with less liquidity when combined with payment streams from the other two systems. Again, this indicates particularly strong liquidity complementarities among the systems. It should also be noted that while the combined payments settle without delay using more liquidity, a close examination of Table 2 shows that the new system settles at an earlier hour of the day than the current BOJ-NET, when participants are endowed with sufficient liquidity to settle payments without delay.

4. Optimizing funding levels

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

A feature of the new system is that funding for the new accounts can be supplied from the standard accounts at any time of the day. To some degree, this option simplifies the problem for participants regarding the amount of funding to transfer to the new accounts at the start of the processing day, as any shortfalls or overages in funding can be corrected during the day.

When designing a payment system that uses a liquidity-saving mode of operations as well as a pure RTGS mode of operations, one question designers face is whether to create another account, as in the BOJ-NET's new accounts. One choice is simply to rely on a single account, and have participants decide on the priority of the payment, in other words, decide whether to send the payment instruction in a pure RTGS or in a liquidity-saving mode. The liquidity-saving mode then relies on incoming funds over a period of time as well as offsetting. Such a choice is described by Johnson, McAndrews, and Soramäki [2004]. In the case of the new system, the computational requirements of BOJ-NET are reduced considerably with the introduction of the new accounts.

The efficiency of the new system could potentially be negatively affected if participants were to transfer funds into and out of their new 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 operations of the algorithm. Because of this potential negative effect of rapid changes in funding levels, it may be useful to conduct the following thought experiment. Suppose, contrary to the design of the new system, that participants could only fund their new accounts twice during the day, at the opening of the processing day and for settlement of their unsettled queued payment instructions at 16:00. Under that counterfactual assumption, what would be efficient levels of initial funding?

Higher levels of initial funding will be associated with a faster rate of intraday settlement, and a higher proportion of payments settled prior to 16:00. There is, however, 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 benefits from a faster rate of intraday settlement, and a benchmark level of costs of intraday funds. Similarly there is no clear measure of increases in credit and liquidity risks 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 a level of unsettled payments at 16:00 is no greater than it is in today's large-value payment systems.

Consider the following problem.

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

$$b_i \geq 0$$

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

It seeks to minimize the sum of initial balances of each participant i in the new account (b_i), under the constraints that a set of payments that day is fixed and given by

P_{ij}, that the balances are non-negative, and that settlement (in a value term) under the new system procedures over a given time interval during processing is at least as high as a rate of settlement S, where S is some yen-rate of settlement per h minutes of the day.

By examining the structure of the problem, 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 the total settlement as an extra yen added to any other participant's initial balance. We can infer that because the variables of initial balances enter the objective function in an additively separable way, there cannot be any way, at the optimal level of balances, to shift balances among accounts (holding fixed the sum of balances) and increase a 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 a rate of settlement by the same amount regardless of into whose account that yen is added.

The problem outlined above is not fully specified, as it does not contain full richness and complexity of the settlement algorithms used by the new system. Nonetheless, an examination of the problem clarifies the heuristic strategy we employ in seeking the efficient levels of initial funding for the new accounts. First, notice that a rate of settlement is specified as the sum of all payments settled. The goal is therefore not to increase a particular participant's rate of settlement, but to increase a rate of settlement for the whole system. Second, the problem seeks to minimize the sum of initial balances, not any participant's initial balance. Thus the efficient levels of funding we discuss are characterized by the following three factors: the total level of funding, the distribution of balances across participants, and the timing of funding.

5. Simulations and results

To find a locally optimum distribution of balances using simulations on historical data would require a large number of simulations. It is rational that we rely on that feature of the optimum levels of initial balances to guide the following heuristic strategy to characterize the efficient levels of balances. We first simulate the working of the new system starting with various levels of initial balances. After each simulation we examine the performance of the system in terms of the value of payments settled prior to 16:00, the value of the remaining unsettled payments at that time, the value of additional amounts that need to be paid in to settle all the remaining unsettled payments, and the value-weighted average time of settlement. We also examine the effects of alternative levels of balances on the system as a whole, and on a separate basis, for the five largest banks and all the other participants. We then investigate the intertemporal distribution of balances as we seek a local optimum distribution of balances.

The results of these simulations give participants and planners a sense of how the alternative levels of balances would affect the system's performance.

Four baseline simulations

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

Another baseline simulation is to endow participants with the exact amount of funds (in the new accounts) equal to that day's multilateral net debit of each participant, given that day's payments history. A participant's multilateral net debit is the amount it would owe to settle its payments if the system were a DNS system. In general, participants do not necessarily know their own multilateral net debits in advance. This scenario can be thought of approximating the case in which participants make pay-ins throughout the day as they gradually learn the exact size of their multilateral net debit. The multilateral offsetting operations may be one way participants do learn the amount of their multilateral net debits, and this scenario approximates the learning process by assuming that they know the amounts with certainty in advance. These simulations are referred as the *exact multilateral net debit (MND) funding* simulations or *progress-payment approximation* simulations.

The third baseline simulation endows participants with their average multilateral net debit funding, where the average is taken over the ten days of the sample period. This scenario is first to assume that participants fund their new accounts in the morning and then make another pay-ins to the new 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 amount used in the *exact MND funding* simulations. However, because it is an average, some payments on some days will remain unsettled at 16:00. These simulations are referred as the *average multilateral net debit (MND) funding* simulations.

The fourth baseline simulation endows participants with half the amount of funding as in the *average MND funding* simulations. These simulations are referred as the *half average multilateral net debit (MND) funding* simulations.

Figure 2 Overview of the performance of the new system
Source: Authors' calculation.

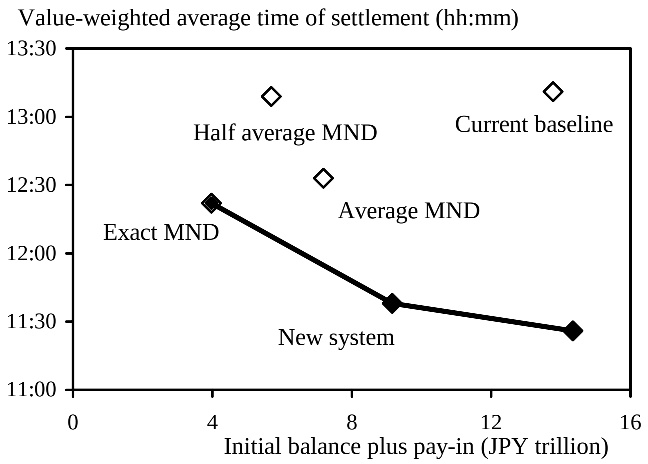


Figure 2 summarizes the performance of the new system described in Section 3 and of these four baseline simulations. Points in the lower-left corner of the chart are more desirable combinations of total balances and settlement time. It can be found that conducting these baseline simulations attempts to search the local optimum level around the point at which participants are endowed with sufficient liquidity only to settle their multilateral net debits.

Table 3 shows the performance of these four baseline simulations on average across the ten days of the sample period with regard to the amounts of initial balances used in the simulations, the additional amounts of pay-ins to the new accounts that would be required after 16:00 to settle those payments that still remain unsettled at that time, the cumulative amounts settled by 16:00, the gross amounts unsettled at 16:00, and the value-weighted average time of settlement. Because the analysis of only ten days yields a small sample, we simply examine averages without considering the statistical significance.

Table 3 Averages from the baseline simulations

Source: Authors' calculation.

Note: Figures in brackets are ratios of each item to that of the *current baseline* simulations. "Five LBs" stands for five largest banks.

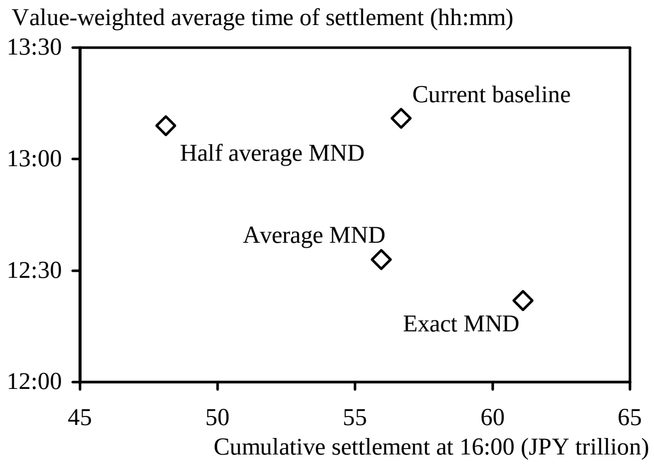
JPY billion; hh:mm

	Initial balances	Five LBs' 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 (-)	13:11
Exact MND	3,975 (0.288)	492 (0.142)	0 (-)	61,106 (1.078)	8,192 (0.649)	12:22
Average MND	3,964 (0.288)	492 (0.142)	3,224 (-)	55,954 (0.987)	13,344 (1.057)	12:33
Half average MND	1,982 (0.144)	246 (0.071)	3,712 (-)	48,119 (0.849)	21,180 (1.678)	13:09

The *exact MND funding* simulation clearly settles more payments by 16:00 with the initial balances as small as one-third of those the *current baseline* simulation requires. The *average MND funding* simulation also has the same qualitative results relative to the *current baseline* simulation, using fewer initial balances than the *current baseline* simulation. The *average MND funding* simulation results that payments unsettled at 16:00 reach up about 20 percent of that day's total payments. These payments would be settled with an additional pay-in of JPY 3.2 trillion, so that the total liquidity used in these simulations is about twice as high as in the *exact MND funding* simulation. The amounts settled by 16:00 in the *half average MND funding* simulation is far less than those in three other scenarios, though economizing too much of initial balances. The *half average MND funding* simulation settles on average only slightly more quickly than the *current baseline* simulation, using much less liquidity than the *current baseline* simulation. Because of its larger pay-in after 16:00, the *half average MND funding* simulation uses almost as much liquidity in total as the *average MND funding* simulation.

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, meaning a larger value settled in a quicker manner, and *vice versa*. The four scenarios can be roughly arranged in the desirable order as the *exact MND funding* simulation, the *average MND funding* simulation, the *current baseline* simulation, and the *half average MND funding* simulation.[8]

Figure 3 Value-weighted average time of settlement and total value settled by 16:00
Source: Authors' calculation.



Overall, the *exact MND funding* simulation settles payments most quickly and largely,

[8] The *current baseline* simulation may be better-off than the *average MND funding* simulation, depending on the shape of indifference curves assumed. For example, the former gets better-off if giving a high preference to settlement completion by 16:00.

and uses less liquidity than the *average MND funding* simulation. This suggests that if participants were to make pay-ins during the day in line with their multilateral net debit positions, they might be able to have fewer payments unsettled after 16:00. In comparing the performance of the *average MND funding* simulation and the *half average MND funding* simulation, the latter settles fewer payments by 16:00, and has a later average time of settlement (although it also settles payments more quickly than the *current baseline* simulation on average). It has approximately 25 percent of the payments unsettled at 16:00. To settle these payments it requires an additional pay-in of JPY 3.7 trillion. The *half average MND funding* simulation, after all, uses about 80 percent of liquidity used in the *average MND funding* simulation, after taking into account the large pay-ins at the end of the day. This result reminds one that as one limits the initial amount of liquidity available to the system, larger pay-ins will be required later in the day.

The results of these four baseline simulations suggest that the new system may perform quite satisfactorily with levels of liquidity that are significantly lower than those currently used in settlement of the three systems. In addition, the behavior of a rough approximation to the progress payments suggests that participants may be better able to conserve funding by making pay-ins to the system during the day, as they learn the multilateral net debit resulting from that day's payments.

Distributional funding simulations

As the results of the *exact MND funding* and *average MND funding* simulations have suggested, the different distribution of initial balances across participants leads to the different performance of intraday settlement even when the total balances in the system are the same.

It is well known that there are a few hub-like participants in Japan's interbank payment network.[9] They play a significant role to redistribute liquidity in the system, by making outgoing payments and receiving incoming payments continuously during the

[9] For the structure of Japan's payment network, see Inaoka *et al* [2004] and Bank of Japan [2006a].

day. Therefore the malfunctioning of these hub-like participants potentially makes negative effects on the performance of the system as a whole.

In this section, in addition to the baseline simulations, we perform some additional simulations that show the effects of small changes in the funding provided by the five largest banks, which are known to work as hub-like participants in BOJ-NET. These simulations are conducted with the other participants in the system being endowed first with the exact multilateral net debit funding, and, for the second set of these simulations, with half that level of funding. Because those participants are endowed with the exact amount of their multilateral net debit, these simulations are probably best compared with the *exact MND funding* simulation. The amounts that the five largest banks 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. So these simulations are indicative of a situation in which all but the five largest banks make regular progress payments in the amounts of their multilateral net debits, and the five largest banks supply very little in the initial funding amounts. These simulations are not meant to model the actual behavior of participants, but rather to investigate the possible behavior of the new system as we vary the funding of some particular participants in different ways.

These simulations are quite 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 the paper.

The first set of simulations shows that reducing the five largest banks' total funding from JPY 492 billion, as in the *exact MND funding* simulation, to JPY 18 billion does not substantially reduce the speed of settlement in the system (see Table 4). The value-weighted average time of settlement changes from 12:22 to 12:34. Nor is the total amount settled by 16:00 reduced appreciably, even though the largest five banks had multilateral net debits of approximately JPY 500 billion on the sample days. These results show that individual participants, or even groups of participants, may significantly reduce their initial level of funding without necessarily causing proportional changes in the amounts settled. Note that these results come at the cost of large amount of end-of day pay-ins. Further research could determine the local optimum in the initial funding amounts.

Table 4 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. "Five LBs" stands for five largest banks.

JPY billion; hh:mm

	Initial balances	Five LBs' 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 (-)	12:22
+90percentile	3,500 (0.881)	18 (0.036)	1,527 (-)	58,170 (0.952)	11,129 (1.359)	12:34
+90percentile*2	3,518 (0.885)	35 (0.071)	1,452 (-)	58,495 (0.957)	10,803 (1.319)	12:34
+90percentile*3	3,535 (0.889)	53 (0.107)	1,405 (-)	59,025 (0.966)	10,274 (1.254)	12:33

Table 5 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. "Five LBs" stands for five largest banks.

JPY billion; hh:mm

	Initial balances	Five LBs' 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 (-)	12:33
+90percentile	3,490 (0.880)	18 (0.036)	3,398 (1.054)	54,172 (0.968)	15,128 (1.134)	12:43
+90percentile*2	3,507 (0.855)	35 (0.071)	3,371 (1.046)	54,056 (0.966)	15,243 (1.142)	12:42
+90percentile*3	3,525 (0.889)	53 (0.107)	3,366 (1.044)	54,621 (0.976)	14,678 (1.100)	12:41

The second set of simulations endows all but the largest five banks with their average multilateral net debit amounts, as in the *average MND funding* simulations (see Table 5). The largest five banks are again endowed with an amount that is equal to the size of the payment that is at the 90th percentile of their payment size distribution on the current BOJ-NET alone. In this simulation, which is best compared with the *average MND funding* simulations, we see that the performance of the system remains quite good even though the largest five banks' funding levels are reduced substantially. The amounts settled by 16:00 falls by only 3 percent, and the value-weighted average time of settlement occurs 10 minutes later.

A final set of these simulations, in which participants other than the largest five banks have their initial funding levels set at half of the day's multilateral net debit, confirms the result that dramatically reducing the funding levels of the largest five banks does not reduce settlement by that proportion (see Table 6).

Table 6 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. "Five LBs" stands for five largest banks.

JPY billion; hh:mm

	Initial balances	Five LBs' 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 (-)	13:09
+90percentile	1,754 (0.885)	18 (0.071)	3,756 (1.012)	46,017 (0.956)	23,282 (1.099)	13:19
+90percentile*2	1,772 (0.894)	35 (0.142)	3,724 (1.003)	46,350 (0.963)	22,948 (1.083)	13:18
+90percentile*3	1,789 (0.902)	53 (0.214)	3,720 (1.002)	46,494 (0.966)	22,804 (1.077)	13:17

In each set of the simulations just discussed, we vary the funding levels of the five largest banks by endowing them with multiples of JPY 18 billion, namely 35 (doubled) and 53 (tripled) for their initial balances. These increases in the levels of initial balances do not appreciably change the outcome. One reason is that liquidity-saving features effectively reduce some distortions from optimal balances by running offsetting mechanisms continuously during the course of the day. Offsetting mechanisms can relax conditions for gross settlement in comparison with a pure RTGS mode, and then achieve relatively smoother flow of payments despite the distortions of initial distribution of balances.

In general, there tends to be a greater amount settled as the initial funding levels of the largest five banks increases, but this is not always true. For example, raising the largest five banks' initial funding from JPY 18 billion to 35 slightly reduces the amounts settled by 16:00 in the second set of simulations. This result implies that the amount settled by 16:00 is not a monotone increasing function of some particular participants' initial balances.

Progress-payment simulations

The *exact MND funding* simulation has endowed participants with the exact amounts of the multilateral net debit at the beginning of the processing day. This simulation can also approximate the case in which participants make pay-ins continuously during the day as they learn the size of their multilateral net debit in that day. The question is how the performance in the system can be affected if the timing of intraday pay-ins is changed.

Table 7 Averages from the *progress-payment approximation* simulations (1)

Source: Authors' calculation.

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

JPY billion; hh:mm

	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 (-)	13:09
+ Exact MND at 10:00	1,982 (1.000)	6,095 (-)	2,780 (0.749)	61,621 (1.281)	7,678 (0.362)	11:51
+ Exact MND at 12:00	1,982 (1.000)	5,571 (-)	2,302 (0.620)	62,681 (1.303)	6,617 (0.312)	12:10

Table 8 Averages from the *progress-payment approximation* simulations (2)

Source: Authors' calculation.

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

JPY billion; hh:mm

	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 (-)	13:09
+ Half exact MND at 10:00	1,982 (1.000)	3,047 (-)	3,202 (0.862)	59,152 (1.229)	10,146 (0.479)	12:15
+ Half exact MND at 12:00	1,982 (1.000)	2,785 (-)	3,094 (0.834)	59,076 (1.228)	10,223 (0.483)	12:30

It has been already described that the *half average MND funding* simulation substantially underperforms the *exact MND funding* simulation, because of the severe liquidity constraints in the system. In the progress-payment simulations, starting with the half average multilateral net debits and then making intraday pay-ins at 10:00 or 12:00, both the value settled by 16:00 and average time of settlement can approach to those of the *exact MND funding* simulation (see Table 7 and 8). The high performance of the progress-payment simulations with intraday pay-ins comes at the cost of twice as large amount of the total liquidity in the *exact MND funding* simulation.

In comparing the scenarios with additional pay-ins at 10:00 and at 12:00, both of them can achieve almost the same level of the value settled by 16:00. The average time of settlement, however, is further improved with the additional pay-ins at 10:00 rather than with the additional pay-ins at 12:00. The earlier arrangement reduces the duration of the payments unsettled, and then leads to the earlier average time of settlement. In comparing the performance of the intraday pay-ins with the exact multilateral net debit and the half of that, the latter settles fewer payments by 16:00, and has a later average time of settlement.

Participants are required to add intraday pay-ins at the appropriate timing to secure the sufficient funding. With such a careful management of liquidity and payment flows, smoother flow of payments can be achieved in the system. However, participants can learn the optimum timing of funding only *ex post*. The second-best solution to the optimum funding problem subject to a certain rate of settlement is, therefore, to endow participants with the exact amount of the multilateral net debit at the beginning of the processing day.

6. Concluding remarks

The new system with liquidity-saving features will require the level of liquidity less than that necessary for intraday settlement in the current BOJ-NET. In the paper, we have explored characteristics of the optimum funding level in the new system using simulation analysis. More specifically, we have analyzed how quickly intraday settlement could occur if the level of initial funding were subject to some liquidity constraints. Our findings are summarized as follows.

(1) To minimize the total balances in the system subject to a certain level of the progress rate of intraday settlement, participants need to secure timely funding, and to appropriately distribute the total balances across them in the system. In fact, the timing of funding may actually be less controllable because participants could hardly learn the optimum timing of funding *ex ante*. The simulation results suggest that it is one of the second-best arrangements for the local optimum of balances to endow participants with the multilateral net debit amounts at the beginning of the processing day.

(2) Offsetting mechanisms search for a set of payment instructions that can be settled when taking into account incoming payments as source of liquidity as well as actual balances in accounts at that point. These mechanisms have side effects on the cross-sectional and intertemporal distribution problem of balances in the system. Through relaxing conditions for gross settlement, these mechanisms are expected to conduct some fine-tuning during the course of the day to reduce a certain level of distortion from optimum balances.

(3) The simulation analysis also indicates strong economies of scale in liquidity use in Japan's large-value payments. It suggests that participants enjoy liquidity efficiencies in combining the different payment streams rather than in operating individual payment systems separately.

Solving the optimization problem for funding by using simulation analysis would require a large number of simulations. Although this work is supposed to be quite time consuming, it gives participants and planners a sense of how alternative levels of funding would affect the system's performance.

Appendix

Offsetting algorithms in the new system

Offsetting mechanisms search for a set of payment instructions that can be settled when taking into account incoming payments as source of liquidity, and settle the selected instructions simultaneously. In the new system, a bilateral offsetting algorithm will run continuously throughout the day, with a multilateral offsetting algorithm running a few times a day to complement the bilateral offsetting algorithm.

The bilateral offsetting algorithm will search for a pair of bilaterally offsetting payment instructions or a single instruction that can be settled on a gross basis. It will run when one of the following events occurs: (i) a new payment instruction entering the system; (ii) an increase in balances of the new account; (iii) a change in the payment instruction at the top of the queue due to settlement, reordering, or cancellation. The target payment instruction for bilateral offsetting is the newly submitted payment instruction when (i) occurs, and the top-queued payment instruction when (ii) or (iii) occurs.

For example, where the target payment instruction is a newly submitted payment from Bank A to Bank B, the system searches from the top of the queue for a payment instruction from Bank B to Bank A that can be settled simultaneously using available balances.

The multilateral offsetting algorithm will run at fixed times. It will attempt to find the largest set of queued payment instructions that can be settled using available balances by first testing to settle all queued payment instructions at once, and successively removing the largest queued payment instruction from the participant with the largest funding shortfall until a set of payment instructions that causes no funding shortfalls can be found.

Profile of the 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.[10] Highly complicated offsetting algorithms with a settlement-value maximization or time-weighted average settlement-value maximization mode are available on the BOJ-NET simulator as well as standard offsetting algorithms based on a FIFO ordering rule, which are described above.

Simulation data

The simulations are performed using Japan's actual data of ten consecutive business days in September 2003. The data includes the following transactions: money-market transactions (excluding those with the Bank of Japan); foreign exchange yen transactions (excluding CLS related transactions), which are handled either on a DNS mode or an RTGS mode in FXYCS; and the large-value retail credit transfers, which are JPY 100 million and over per transaction. See Table 9 for a summary of those basic statistics.

Table 9 Basic statistics on the simulation data

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

JPY billion

	Daily average volume	Daily average 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 Zengin transactions	13,783	9,483	0.688	1.483

Measurement of simulation results

A settlement delay of a payment instruction can be calculated as the time difference between the payment submission to the system and the completion of the payment. We use two types of statistics to measure a settlement delay in the system: the value-weighted average time of settlement, and the indicator of settlement delay.

[10] See Leinonen and Soramäki [1999] for the Bank of Finland Simulator.

The value-weighted average time of settlement ($VWATS$), which is the average time (measured from the opening of the processing day) weighted by the value of payments settled, is defined as follows:

$$VWATS = \sum_i t_i \cdot v_i \Big/ \sum_i v_i \ ,$$

where t_i and v_i represent respectively the settlement time (minutes) and the value of a payment i. If all payments are settled at the opening of the processing day (9:00), then $VWATS$ has a minimum value of zero minutes because $t_i = 0$ for all i. If no payments are settled during the day, and if all the payments are settled at the end of the processing day (16:30), then $VWATS$ takes a maximum value of 450 minutes because $t_i = 450$ for all i.

In the meanwhile, the indicator of settlement delay (ISD) is defined as follows:

$$ISD = \sum_i \left(t_{2,i} - t_{1,i}\right) v_i \Big/ \sum_i \left(t_{end} - t_{1,i}\right) v_i \ ,$$

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

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