CHIPS Review

Assessing the Efficiency of CHIPS: FNA Simulation prepared for The Clearing House

January 2023

Contents

Introduction

This document describes the independent review of The Clearing House Interbank Payment System (CHIPS) by FNA for The Clearing House, the operator of CHIPS. Following an executive summary, Section 1 provides an overview of the CHIPS system and its settlement algorithms. Section 2 uses real CHIPS payments data to assess the CHIPS system and compare it to several other real and hypothetical systems; Section 3 presents results from additional analyses that go beyond the benchmarking exercise of Section 2; and Section 4 presents conclusions from our review of the CHIPS system.

Executive Summary

Simulation is a vital tool for understanding complex dynamics in modern financial infrastructures. Simulations provide a laboratory setting, wherein one can analyze the probable effects of different system designs, disrupted payment flows or liquidity shortages. Importantly, simulation models can be built to replicate the actual operating environment and can be used for testing and observing scenarios that are not normally found in real operating environments. This capability is invaluable when studying different crisis scenarios and evaluating how to best prepare for and mitigate against them.

FNA is a leader in advanced network analytics and simulation. Our founder and CEO, Dr Kimmo Soramäki, developed the first market infrastructure simulation over two decades ago at the Bank of Finland (Koponen and Soramäki, 1998). Today, FNA's technology and expertise are trusted by the world's largest central banks, payments systems, central clearing counterparties, and commercial banks.

For this report, FNA has been using its simulation technology to assess the efficiency of The Clearing House Interbank Payment System (CHIPS), the US-based private large-value payment system. This report aims to answer the following question: Given CHIPS liquidity and payments, how does the CHIPS system compare with other payment systems in terms of performance and, in particular, payment delays? We use replicas of two G7 large-value payment systems as well as four hypothetical RTGS configurations with advanced liquidity-saving mechanisms. We find that CHIPS compares very favorably to all.

We also deploy FNA's proprietary payment scheduling algorithm, FNA Orchestrate, to the CHIPS simulation. We demonstrate how it can significantly further reduce the liquidity required to settle all payments in the system.

Key Benchmarking Results

Overall, CHIPS compares favorably to both the real G7 large-value payment systems and the hypothetical RTGS configurations with advanced liquidity-saving mechanisms. Below we have selected and summarized some highlights from the study.

Average payment delay

Average payment delay denotes the average time that a payment remains unreleased and, thus, unsettled after submission to CHIPS due to insufficient liquidity or position limits. Of the systems evaluated, CHIPS has the second-lowest average delay time, with the two G7 systems ranking first and third. The average payment delay is also more variable across days in CHIPS than in the first ranking system, with days showing higher total value tending to correspond to higher payment delays.

Weighted delays

When weighting the delay by the value of payments, CHIPS performs best overall. This is arguably a more interesting and informative metric than average delay time, as the delay of a higher-valued payment is likely more detrimental than the delay of a lower-valued payment. Section 3 explains in more detail how the timing of the different settlement algorithms in each system affects the payment delay performance measures.

Payments throughput

The payments throughput metric measures the proportion of payments whose (unweighted) delay times were less than one minute, between one and 15 minutes, and greater than 15 minutes. Of the systems evaluated, CHIPS has the second-highest proportion of payments that are settled within a minute.

Payment Batching

Payment batching refers to the proportions of payment value that were settled gross, bilaterally, and multilaterally. The two G7 systems were the most comparable to CHIPS, with the majority of value settled gross. However, CHIPS has relatively more value settled multilaterally while the two G7 systems tend to settle more value bilaterally.

Intraday metrics

CHIPS outperforms the other systems for both intraday coverage ratio and liquidity efficiency ratio - calculated at four intervals during the day. All systems were almost equal by the end of the day.

FNA Orchestrate

Often payments are known to participating banks much earlier than they are sent to CHIPS. FNA research has shown that FNA's Orchestrate algorithm, which optimizes the settlement order of these known payments so that payments can be settled using less liquidity, can lead to reductions in liquidity use close to those seen with multilateral netting (without the need for netting).

We find that by reordering payments, CHIPS could settle all payments using on average **22% less liquidity** than the existing CHIPS funding requirements. This is an **average savings of $15.1 billion per day, ranging from $5.5B to $35.5B across the simulated days.**

1. System Overview

CHIPS (The Clearing House Interbank Payment System) is a US-based private large-value payment system operated by The Clearing House Payments Company, LLC, which is owned by a subset of CHIPS' 45 participant banks. On a typical operating day, CHIPS settles nearly half a million payments worth approximately $1.7T. CHIPS provides intraday settlement finality, and its settlement algorithms allow for fast settlement with low funding requirements.

1.1 Funding and Risk Controls

CHIPS participant banks can maintain two prefunded positions in the system, referred to as the primary position and supplemental position. The primary position is initially equal to the pre-funded amount (PFA) that each bank funds at the start of each business day; i.e., the pre-funded amount, once funded, is the opening primary position. The pre-funded amounts are calculated using historical data and updated weekly. Banks may also choose to provide supplemental funds during the day, which are accounted for as a supplemental position.

When a CHIPS payment is settled using a sending participant's supplemental position, the receiving participant's supplemental position is credited. Hence, even if a participant has not provided supplemental funding, it can have a supplemental position as a result of receiving payments that were settled using the sending participant's supplemental position.

Banks' primary and supplemental positions have a non-negative balance requirement. In addition, a bank's primary position may not exceed twice its pre-funded amount prior to 3 pm, when CHIPS raises the limit on the maximum position a participant may have. This upper limit on the primary position, also referred to as the position limit, was designed to prevent any banks from becoming liquidity sinks and to maintain the flow of liquidity throughout the system. The supplemental position has no upper limit.

The primary position cannot be changed during the day except by settling payments (i.e., no additional funds can be added post-pre-funding, and no funding can be withdrawn). This is not the case with the supplemental position, where funding and withdrawals can be made throughout the day. Participants may reserve some or all of their supplemental position. In that case, the reserve amount is earmarked for high-priority payments and cannot be used for payments of lower priority. There is also an Auto Reserve option which automatically reserves supplemental funding for high-priority payments.

Currently, in CHIPS, the only constraint on supplemental withdrawals (i.e., withdrawals of funds equal to some or all of a participant's supplemental position) is the positive balance requirement. Previously, including during the time period of the CHIPS data used for the benchmarking exercise presented in Section 2, banks could only withdraw funds equal to the amount of supplemental funding they had provided.

1.2 Payment Sizes and Priorities

Payments are classified by both their priority and size. Payment priority falls under three possible priority levels – 1, 2, and 3 – with 3 being the highest priority and 1 being the lowest priority. The vast majority of payments (over 99% by both value and volume) have priority 1. The payment size is separated into small, medium, or large value. Large payments are those with value higher than 80% of the sending bank's PFA; small payments are those with value lower than 20% of the sending bank's PFA; and the remaining payments are classified as medium. Although the payments are designated as small, medium, and large, only the large vs. small/medium distinction is important for payment netting (see Section 1.4).

1.3 Payment Flow

1.3.1 Start of Day Procedures

At the beginning of each business day, each bank deposits an amount equal to its PFA in the CHIPS Prefunded Balance Account at the Federal Reserve Bank of New York. This amount is then reflected on the CHIPS ledger as the participant's opening primary position. A bank may also optionally deposit throughout the day any amount of funds as supplemental funding, which will be reflected on the CHIPS ledger as its supplemental position (or added to an existing supplemental position from prior funding or settled payments). Banks cannot receive payments until they have provided prefunding and submitted at least one outgoing payment. Even if a bank has submitted its prefunding amount, it cannot receive any payments until it first submits an outgoing payment.

1.3.2 Intraday Payment Settlement

Payments are netted in one of two algorithms. The two algorithms run continuously throughout the day, as opposed to at fixed times or every fixed number of payments.

1.3.3 End of Day Procedures

At the end of the day, each participant's primary and supplemental positions are combined into a combined position. Position limits are increased incrementally and netting algorithms are run on any remaining queued payments in the system. This is repeated up to 50 times if there are still unreleased payments, and on the 50th run, position limits are removed entirely. If there are still unreleased payments, CHIPS follows its final funding procedures. If any payments remain unreleased following the final funding procedures, the payments are cancelled by the system.

2. Benchmarking

In order to assess the efficiency of the CHIPS system compared to other possible configurations, we conducted a large simulation study using real CHIPS data and FNA's payment simulator. Recently, McAndrews and Vartin (2022) compared liquidity efficiency among CHIPS, Fedwire, TARGET2, and CHAPS. There is an important distinction between our work and theirs, however. McAndrews and Vartin considered Fedwire performance with Fedwire payments, TARGET2 performance with TARGET2 payments, and so on. This study uses only CHIPS payments to understand how those same payments would have settled under different system configurations (see section 2.3 for further information on the system configurations used in this study). To ensure a fair comparison between CHIPS and other configurations, all simulations used real CHIPS data as well as the same opening hours and opening balances. The study also kept the same supplemental deposits and withdrawals, with forced net settlement of queued payments at the end of the day.

2.1 Payment System Simulation

Simulation is a vital tool for understanding complex dynamics in modern financial infrastructures. Simulations provide a laboratory setting to analyze the probable effects of different system designs, disrupted payment flows or liquidity shortages. Importantly, simulation models can be built to closely replicate the actual operating environment and can be used for testing and observing scenarios not normally found in real settings. Simulations can be carried out to study different crisis scenarios and then evaluate how to best prepare for, and mitigate against them. While realizations of such crisis scenarios are extremely rare, simulation models enable one to study numerous crisis-like situations and thus prepare in advance to best manage a real crisis.

A payment system *simulator*, or simply payment simulator, is a piece of software that mimics the processing and settlement of payments in a real payment system. The input data for payment simulation is the payments themselves (for example, all payments submitted on a particular day, week, or month, consisting of the date, time, sender, receiver, value, and, optionally, priority, of each payment), along with banks' opening balances, overdraft and bilateral limits. The simulator should be configured to match all aspects of the real system, including liquidity saving mechanisms (LSMs), throughput guidelines, end-of-day behavior, and handling of payment priorities. The output from a payment simulation consists of the time each payment was settled and how it was settled (e.g., via gross settlement, bilateral or multilateral offsetting), along with the sending and receiving banks' balances and bilateral and multilateral positions at the time of settlement. Payment simulation is useful, for example, to understand the delay-liquidity relationship in a payment system or to investigate the effects of adding or changing the configuration of LSMs. It can also be used to compare the operating characteristics of different system configurations, as we do here.

Simulations of market infrastructures have been used by central banks and financial market infrastructures for almost two decades, beginning with work at the Bank of Finland in the late 1990s (Koponen and Soramäki, 1998). Simulation studies were also an integral part of the regulatory approval of the Continuous Linked Settlement (CLS) system, which was launched in 2003. CLS is currently the world's largest settlement system, settling on peak days over $9 trillion worth of foreign exchange transactions on the books of 18 central banks (and currencies). The Bank of Japan used simulations to evaluate alternative liquidity-saving mechanisms before implementing them in the BOJ-NET Funds Transfer System (Imakubo and McAndrews, 2006). The Eurosystem has embraced payment system simulations as an ongoing oversight tool by specifying how transaction-level data may be used (EU, 2010), and has developed a TARGET2 simulation platform. McLafferty and Denbee (2012) used real payment data and the FNA Payment Simulator to quantify the liquidity efficiency that could be obtained in CHAPS, the UK's large-value payment system, by the implementation of a liquidity-saving mechanism.

2.2 Inputs and Outputs

The input data for simulations consist of all CHIPS payments (the date, time, value, sender, and receiver) as well as all banks' PFAs and all supplemental funding and withdrawals on each day of June 2020. Bank names were anonymized and replaced with names like Brian and Kirsten, while all other provided data remain as they were in CHIPS. Supplemental funding and withdrawals were modeled in the simulations by creating a dummy bank as the sender for supplemental funding and the receiver for supplemental withdrawals.

The mean daily payment volume in June 2020, was 447,650 payments and ranged from 389,480 (16 June 2020) to 637,116 (30 June 2020) payments. The mean daily payment value was $1.62T and ranged from $1.2T (25 June 2020) to 1.98T (30 June 2020). There were 43 active banks in CHIPS during June 2020, but on most days (17 of the 22 business days) only 42 sent and/or received payments.

CHIPS calculates a suite of daily metrics to monitor system performance. Those metrics are listed and described below. Many of the metrics are not affected by the system configuration (as long as all payments settle by the end of the day, which in CHIPS has always been the case) and their values were used as checks on FNA simulation results.

All metrics listed above were calculated in all FNA simulations. For ease of interpretability, we scale total payments throughput by total payment volume to obtain the average payment delay time. We also included an additional metric that we refer to as *weighted delay*, equal to the sum of payment values multiplied by delay times, and scaled by total payment value. Finally, we also calculate intraday versions of the Coverage Ratio and Intraday Liquidity Efficiency Ratio. Intraday coverage ratio at time X is equal to the value of payments settled up to time X divided by the value of payments submitted up to time X. Intraday liquidity efficiency ratio at time X is equal to the value settled up to time X divided by the total funding up to time X. These metrics are calculated at 7:59 am, 10:59 am, 2:59 pm, and 4:59 pm.

Metric	Description	Affected by System Configuration?
Processed Payments Count	Number (volume) of payments settled	No
Processed Payments Amount	Value of payments settled	No
Total Initial Funding	Sum of all banks' PFAs	No
Total Supplemental Deposits Funding	Value of all banks' supplemental funding	No
Total Supplemental Withdrawals Funding	Value of all banks' supplemental withdrawals	No
Total EOD Final Funding	Total amount final funding provided by banks in with a closing position requirement at end of day	No
Net Supplemental Funding	Total Supplemental Funding - Total Supplemental Withdrawals	No
Total Funding	Total Initial Funding + Net Supplemental Funding + Total EOD final funding	No
Final Ratio	Total EOD Final Funding / Total Funding	No
Liquidity Efficiency Ratio	Processed Payments Amount / Total Funding	No
Supplemental Funding Ratio	Net Supplemental Funding / Total Funding	No
Total Payments Throughput	Sum of payment delay times	Yes
Coverage Ratio	1 - Value of payments settled in EOD netting / Processed Payments Amount	Yes
Payments Throughput	Proportion of payment volume settled in: <1 min; 1 - 15 min; > 15 min	Yes
Payment Batching	Proportion of payment value settled: gross; bilateral; multilateral	Yes

2.3 System Configurations

The system configurations considered in our simulations include RTGS with various standard liquidity saving mechanisms, as well as two actual G7 systems for which we have built replicas. In addition to using the same payments and funding as in the real CHIPS system, our simulations enforced the same opening hours (21:00 the previous day to 17:00.[1]) and end-of-day behavior (force settlement of all queued payments) as CHIPS.

We considered four variations of standard RTGS system configurations. The simplest configuration was RTGS with FIFO settlement order (subsequently referred to as FIFO). This configuration has no LSMs and requires payments to be settled in FIFO order. In the Bypass configuration, payments are allowed to bypass FIFO settlement order, and no other LSMs are implemented. In the Netting configuration, payments are allowed to bypass FIFO settlement order, and queued payments are considered for multilateral netting every five minutes.

The netting algorithm used is that used by the Central Bank of Mexico. First, the Bech-Soramaki algorithm (Bech and Soramäki, 2007) is implemented, and then any remaining payments are re-sorted by value and tested again for settlement. In the Offset + Netting configuration, bypass FIFO and multilateral netting are implemented as in the FIFO and Netting configurations and payments may also be settled using bilateral offset. With bilateral offset, any time a sending bank does not have sufficient funding to settle a payment, the receiving bank's queue is searched for a delayed payment to the sending bank. The first payment that can be settled jointly with the original payment without violating the sender's or receiver's risk controls is selected, and the two payments are jointly settled. Other options for bilateral offset include choosing the receiver's queued payment that minimizes the net value sent or searching for a set of payments in the receiver's queue to minimize the net value.

In addition to the variations on RTGS systems described above, we conducted three additional sets of simulations based on real G7 large-value payment systems (LVPS). Two of the simulation configurations (referred to here as LVPS1 and LVPS2) are variations on a single system, in which payments are tested for settlement in netting cycles taking place every two minutes. The distinction between the two configurations is whether the payments are treated as non-urgent (in which case payments are only tested for settlement in the settlement cycles) or urgent (in which case payments are tested for immediate settlement, and the settlement cycles attempt to settle delayed payments).

The second system configuration (referred to here as LVPS3) tests all payments for immediate settlement and runs a multi-stage settlement algorithm on queued payments every five minutes. In both of these real systems, any payments that remain queued at the end of the day (EOD) are rejected. To make simulation results comparable to CHIPS, we changed the corresponding simulators to allow for forced net settlement of queued payments at EOD. Unlike CHIPS, our simulations do not employ upper position limits.

2.4 Benchmarking Results

None of the system configurations considered in our simulations performed uniformly better than CHIPS; however, some systems outperformed CHIPS on some metrics. As a general rule, adding LSMs improved performance in the RTGS simulations, and all three of the real systems considered consistently outperformed the RTGS with standard LSMs.

2.4.1 Average Delay

Figure 1 gives an overview of the average delay time across all simulation configurations as well as in the real CHIPS system. LVPS2 has the lowest average delay time, followed by CHIPS, LVPS3, and the non-FIFO RTGS configurations. As has been shown in many other studies, these results also illustrate that enforcing FIFO settlement order significantly increases settlement delays.

22 days considered. The mean delay time in CHIPS is 3:57 (daily values range from 2:55 to 5:44) and the mean delay time in LVPS2 is 2:49 (daily values range from 2:03 to 3:35). Thus, on average, LVPS2 settles payments just over one minute faster than CHIPS. The difference in average delay time between the two systems is statistically significantly different from zero, with a p-value less than 0.000001.

Figure 2 also shows that the daily average payment delay is more variable in CHIPS than in LVPS2. While the average delay for LVPS2 ranges from two minutes to just under four minutes per day, the average delay in CHIPS ranges from just under three minutes to nearly six minutes. In particular, the three farthest-right points in *Figure 2* are extreme for CHIPS but not for LVPS2. Those three points correspond to the days with the highest system value in our sample (15, 17, and 30 June).

Figure 1: Average delay time (in minutes) across simulated systems and CHIPS

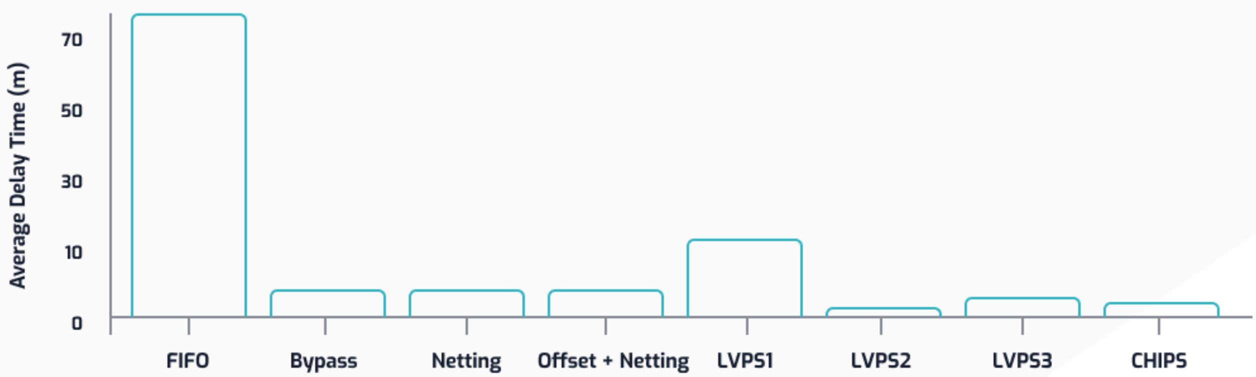


Figure 2 shows a more detailed comparison of the average delay in CHIPS and LVPS2. Each point in the scatter plot represents a single day, and the dashed line represents *y = x*. The fact that all points are below the dashed line means that LVPS2 had a lower average delay time than CHIPS on all of the

We can further investigate this relationship between daily payment value and average delay for the three systems with the lowest average delay: CHIPS, LVPS2, and LVPS3.

Figure 2: Daily average delay time for CHIPS and LVPS2 systems

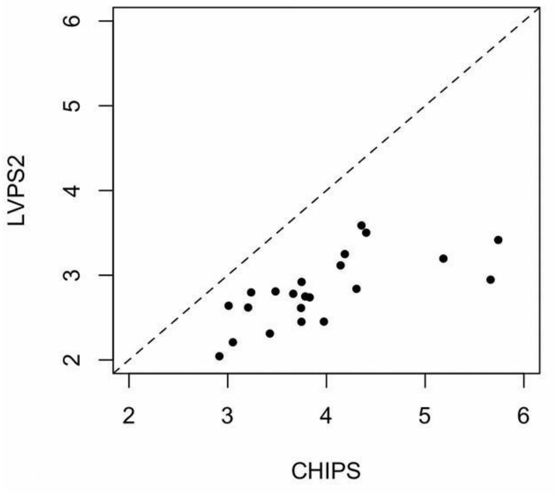


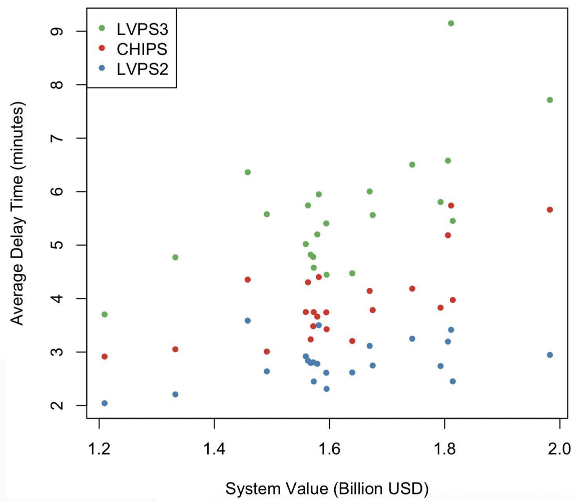
Figure 3 shows all three relationships in a single scatter plot. Each point in the scatter plot represents a single day for a single system configuration, and colors indicate the system configurations. The correlation between system value and average delay is strongest for CHIPS (0.72), followed by LVPS3 (0.67) and LVPS2 (0.41). We found similar, but weaker results for the correlation between system volume and average delay.

Finally, we consider results for individual banks. Although we do not have bank-level metrics from CHIPS, we can calculate them for all simulation configurations. Again we focus on configurations LVPS2 and LVPS3.

In both systems, one bank had the highest average delay time, of about 45 minutes. System configuration can affect different banks differently, however; for example, a different bank had the second-highest average delay time in both configurations, but the mean delay time was about 45 minutes in LVPS3, compared to only about 25 minutes in LVPS2.

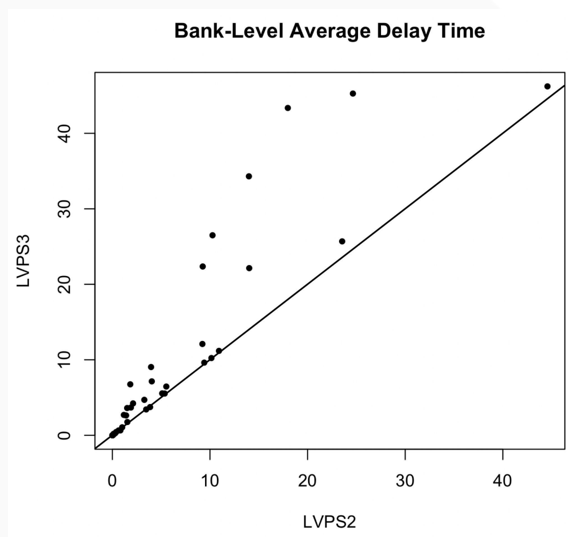
Figure 4 compares the bank-level average delay times for systems LVPS2 and LVPS3.

Figure 3: Relationship between payment delays and system value



Although the majority of banks have fairly small differences between the two systems, there are several banks whose mean delay time is notably higher in LVPS3 compared to LVPS2.

Figure 4: Bank-level average delay time in LVPS2 and LVPS3



2.4.2 Weighted Delay

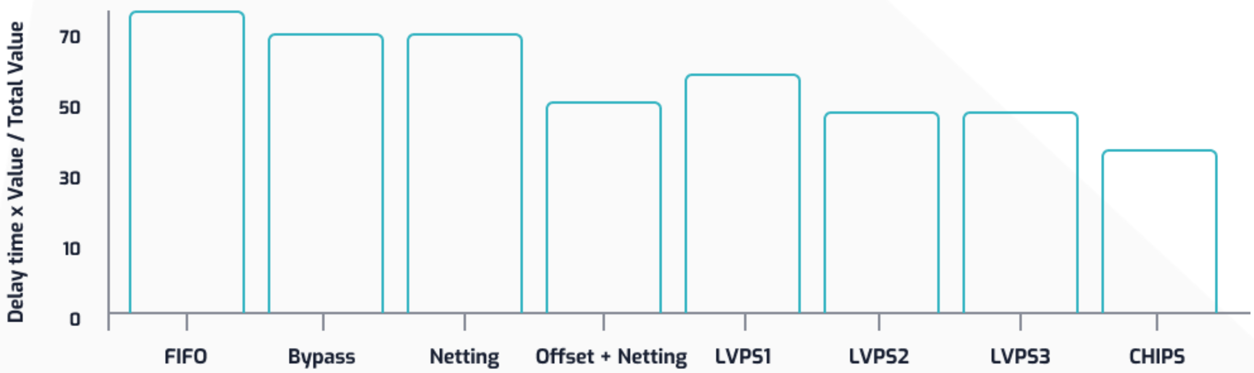
Weighted delay is arguably a more interesting and informative metric than average delay time, as it weights larger-valued payments more heavily. Delay of a higher-valued payment is likely more detrimental than the delay of a lower-valued payment, and the weighted delay metric is largely influenced by long delays of high-value payments.

Figure 5 provides a high-level overview of the average weighted delay in all the system configurations. We see less variability across systems compared to the unweighted delay, but the overall trend remains the same, with FIFO performing the worst, and CHIPS, LVPS2, and LVPS3 performing the best. CHIPS performs the best overall, followed by LVPS3.

both systems. Those two dates had among the lowest system volume in the sample, although weighted delay overall was not strongly correlated with system volume or value in either CHIPS or LVPS3.

At the bank level, we again focus on the two top simulated systems, LVPS2 and LVPS3, due to the lack of bank-level CHIPS metrics. Unlike the average delay metric, weighted delay varies very little between the two systems at the bank level. *Figure 7* shows the scatter plot of bank-level average weighted delay in LVPS2 and LVPS3. The bank-level weighted delay values are scaled by the corresponding bank's outgoing value.

Figure 5: Average weighted delay time across simulated systems and CHIPS



As with average delay in the previous section, we now focus on comparing weighted delay in CHIPS to its closest competitor, LVPS3. *Figure 6* shows the scatter plot of daily weighted delay in the two systems. Here we see a similar but reversed relationship to that shown in *Figure 2*. CHIPS now outperforms LVPS3 on every day in the sample. The difference in weighted delay between CHIPS and LVPS3 is statistically significant, again with a p-value less than 0.000001.

In *Figure 6* we see two points that stand out from the rest. June 12 had notably higher weighted delay in both systems, and June 23 had notably lower weighted delay in

Figure 6: Daily weighted delay for CHIPS and LVPS3 systems

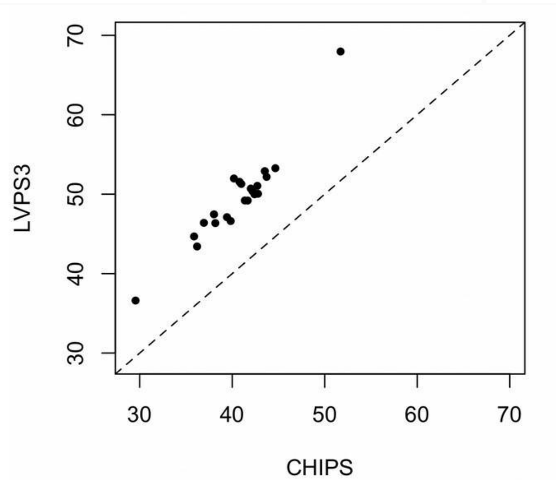
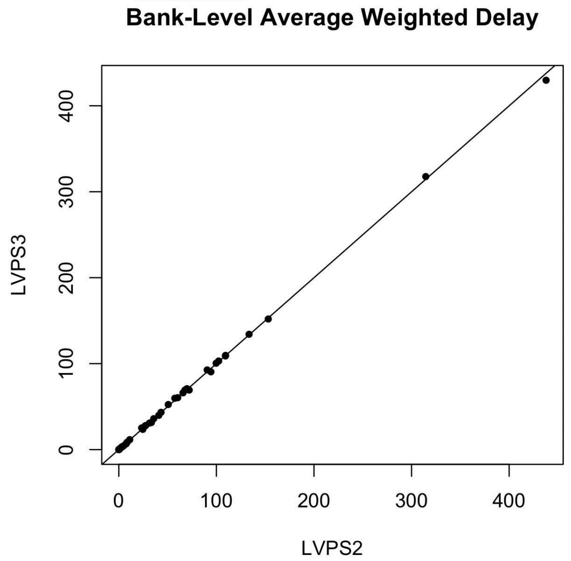


Figure 7: Bank-level weighted delay in LVPS2 and LVPS3



2.4.3 Payments Throughput

The payments throughput metric measures the proportion of payments whose (unweighted) delay times were less than one minute, between one and 15 minutes, and greater than 15 minutes. *Figure 8* shows a high-level overview of these metrics.

We see that CHIPS and LVSP2 had the highest proportion of payments that settled within a minute, while LVPS2 had the lowest proportion of payments that took longer than 15 minutes to settle.

As with average delay, the system closest to CHIPS is LVPS2. We now compare daily values for those two systems. *Figure 9* shows scatter plots for CHIPS versus LVPS2 on each of the three categories of delay time. From the top left panel, we see that CHIPS and LVPS2 are quite similar with respect to the proportion of payments that settle within one minute; the mean difference is less than one percentage point, and the difference is not statistically significantly different from zero ($p = 0.06$). CHIPS and LVPS2 do differ significantly in the other two delay categories: CHIPS has a significantly lower proportion of payments delayed between one and 15 minutes, and a significantly higher proportion of payments delayed by more than 15 minutes ($p < 0.000001$ in both cases). The higher proportion of payments delayed longer than 15 minutes explains why average delay is higher in CHIPS than in LVPS2. It is possible that some of these longer delays in CHIPS are due to inactivity of the receiving bank (since a bank cannot receive payments before it sends at least one payment); more granular CHIPS output data would be needed to know definitively.

Figure 8: Average throughput metrics across simulated system and CHIPS

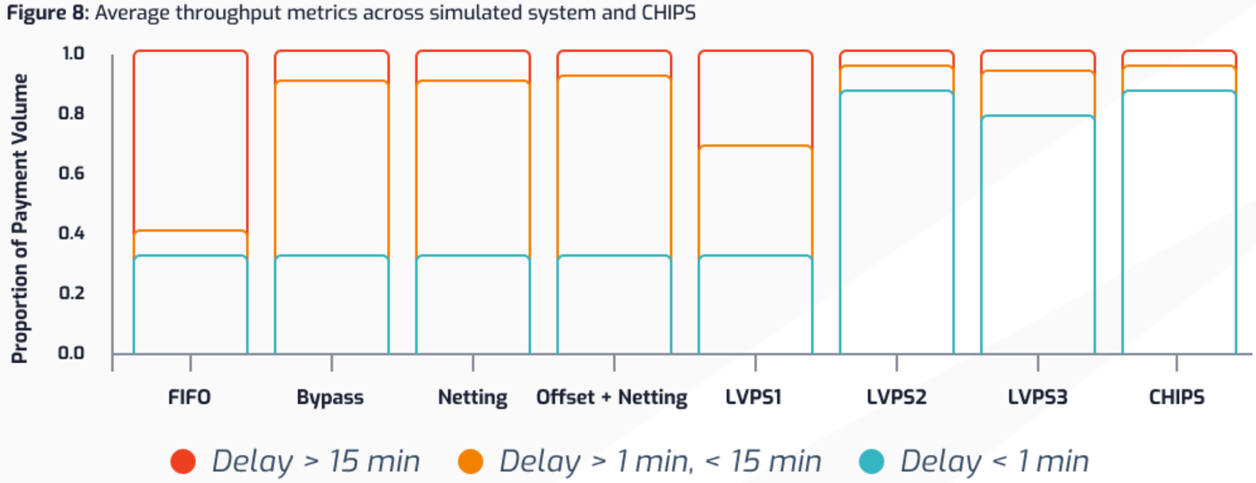
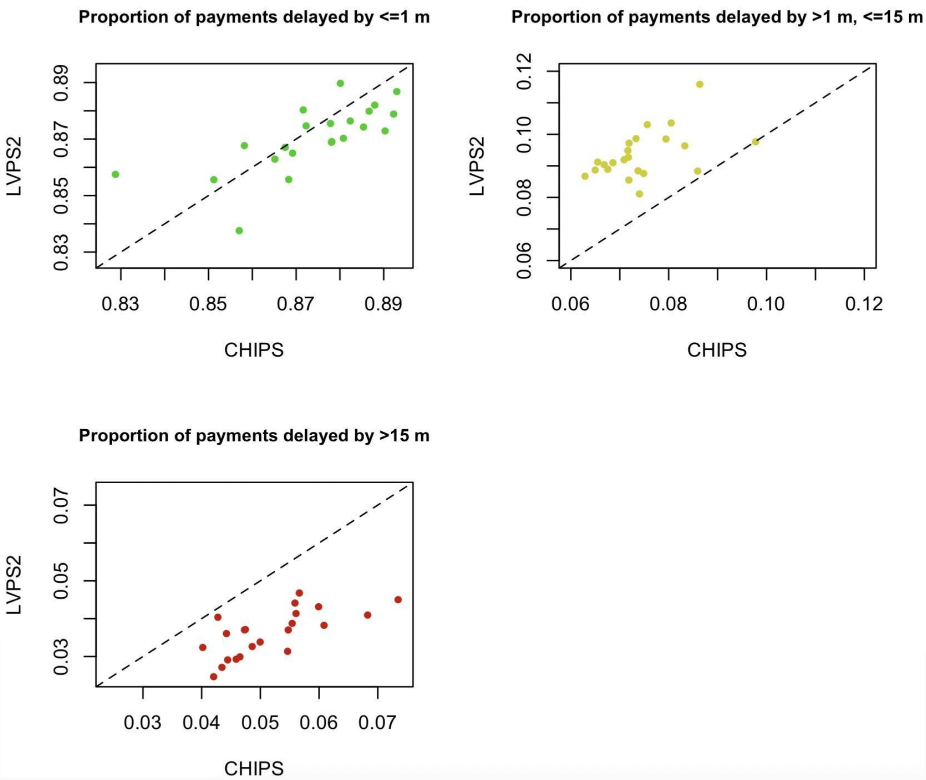


Figure 9: Daily throughput in CHIPS and LVP



2.4.4 Coverage Ratio

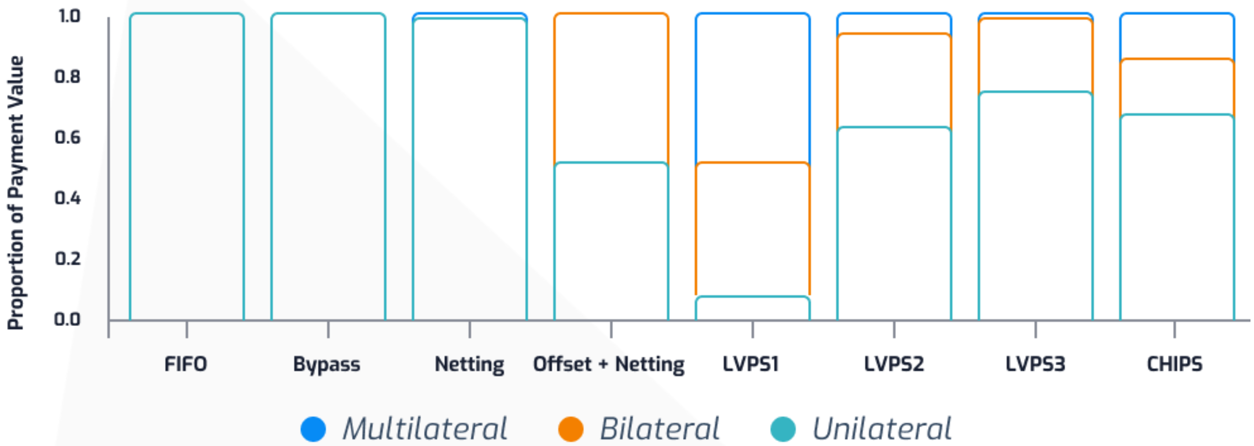
The coverage ratio is equal to one minus the value of payments settled in end-of-day netting divided by the total value of payments settled. We find it varies very little across the system configurations, with all configurations yielding an average daily value of approximately 0.99. CHIPS has the highest average value of coverage ratio, equal to 0.994. However, differences across the systems were not statistically significant.

2.4.5 Payment Batching

Payment batching refers to the proportions of payment value that were settled gross, bilaterally, and multilaterally. *Figure 10* shows these proportions for all of the simulated system configurations as well as CHIPS.

In the FIFO and Bypass systems, which have no netting or offsetting, all payments settle gross. Adding multilateral netting cycles every five minutes results in only a very small proportion of payments settled multilaterally. This is likely due to inefficiency in the settlement algorithm; more frequent netting cycles might also increase the proportion of payments settled multilaterally. Adding bilateral offset results in about half of payment value being settled bilaterally, again with very little value settled multilaterally. LVPS1 shows more value settled multilaterally than in any of the other systems, as well as a large proportion settled bilaterally. In LVPS1, payments are *only* settled in bilateral and multilateral netting cycles until 15 minutes before the end of the day, at which point any queued payments are tested for gross settlement.

Figure 10: Average throughput metrics across simulated system and CHIPS



Hence, the small proportion of payments settled gross. LVPS2 and LVPS3 are the most comparable to CHIPS, with the majority of value settled gross. However, CHIPS has relatively more value settled multilaterally while LVPS2 and LVPS3 settle more value bilaterally.

The large proportion of value settled bilaterally is likely due to the fact that bilateral relationships in CHIPS tend to be very balanced. That is, counterparty pairs typically send and receive about the same amount. This type of balance in a network can be quantified by the network metric *reciprocity*. At the vertex level (bank-level), reciprocity is equal to the ratio of outgoing link weight to incoming link weight (link weights in our case are equal to the daily value sent from one bank to another), averaged over all counterparties and weighted by outgoing link weight. Averaging the vertex-level reciprocities gives a network-level measure of how balanced payment flows are between counterparties. The mean network-level reciprocity in the CHIPS data is equal to 0.97, and ranges from 0.93 to 0.99. For comparison, Soramäki et al. (2007) found that unweighted reciprocity (that is, the proportion of links for which there exists a corresponding link in the opposite direction) in Fedwire payment networks was on average equal to 0.22. Unweighted reciprocity in CHIPS is equal to 0.84 on average, ranging from 0.81 to 0.86.

2.4.6 Intraday Metrics

Finally, we consider intraday values for coverage ratio and liquidity efficiency ratio, calculated at 7:59 am, 10:59 am, 2:59 pm, and 4:59 pm. For both sets of metrics, CHIPS outperforms the other systems early in the day, with all systems being nearly equal at 4:59 pm (one minute prior to system close). *Figure 11* shows the progression of intraday coverage ratio. Please note that, unlike in *Figures 8* and *11*, the bar heights here are cumulative. For each system configuration, the upper bound of the lightest colored bar represents the coverage ratio at 7:59, the upper bound of the next-darkest bar represents the coverage ratio at 10:59, and so on. The fact that the upper bounds of the black bars are nearly identical means that all systems have nearly identical coverage ratios at 4:59 pm.

Figure 11: Intraday coverage ratio

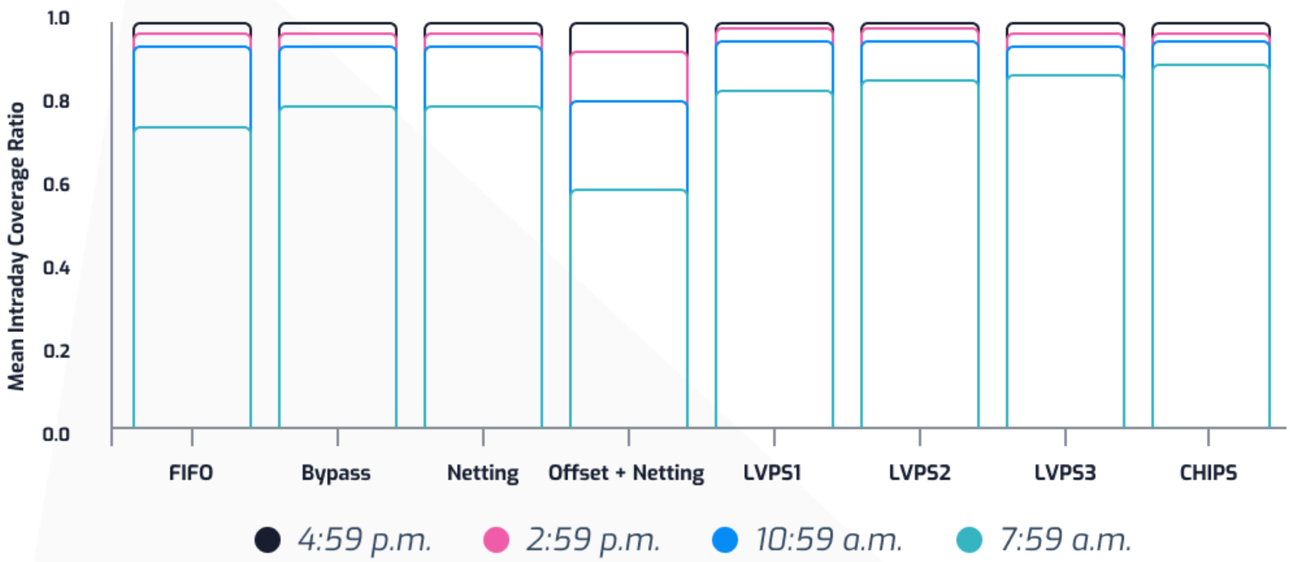
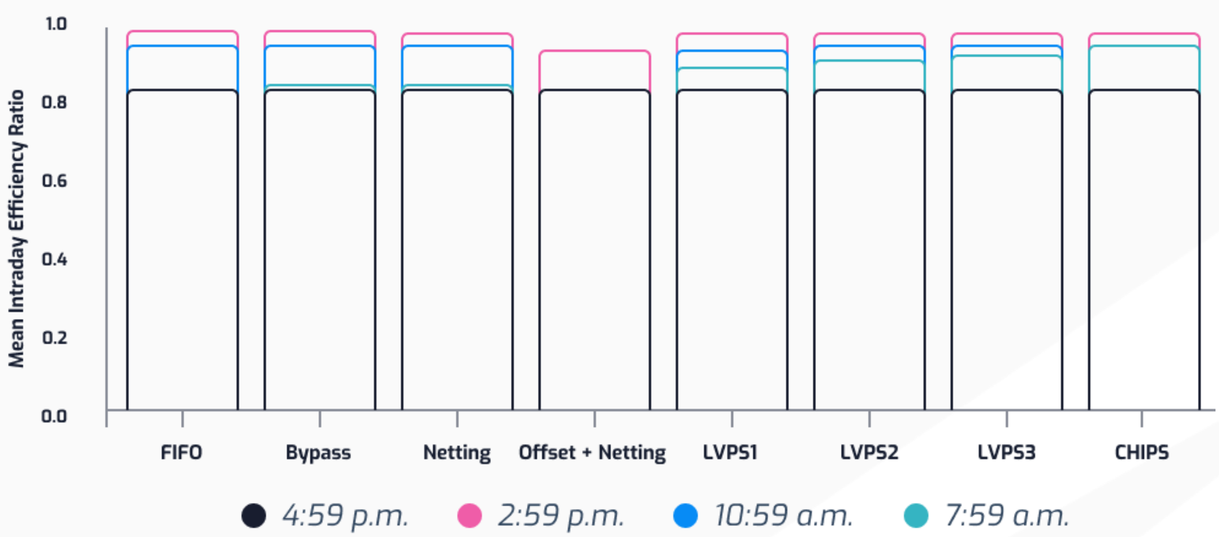


Figure 12 shows the intraday liquidity efficiency ratio. Here we see a similar progression, with CHIPS outperforming the other systems early in the day, and the other systems catching up as the day progresses. Unlike the intraday coverage ratio, however, intraday liquidity efficiency ratio does not increase throughout the day. But rather it increases until the second-to-last time period and then decreases to a near-identical value for all systems. The height of the black bars represents the intraday liquidity efficiency ratio at 4:59 pm.

Figure 12: Intraday liquidity efficiency ratio



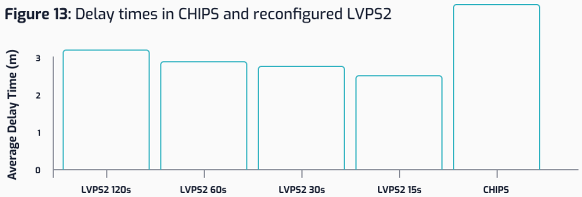
3. Supplemental Analysis

In this section we present two additional analyses that go beyond the benchmarking presented in the previous session to further validate CHIPS performance and suggest directions for potential improvements.

3.1 Reconfiguring LVPS

The benchmarking analysis described in Section 2 showed that none of the system configurations under study uniformly outperformed CHIPS. LVPS2 has shorter delay times on average, but CHIPS outperformed all systems on the arguably more important weighted delay metric. The two system configurations that consistently came closest to CHIPS were LVPS2 and LVPS3. The primary differences between these two systems and CHIPS are different settlement algorithms and different timing of the settlement algorithms, with algorithms in CHIPS running more or less continuously and LVPS2 and LVPS3 algorithms running at fixed intervals. In order to investigate how much the timing of settlement algorithms affects system performance, we conducted additional LVPS2 and LVPS3 simulations with increasingly more frequent settlement cycles.

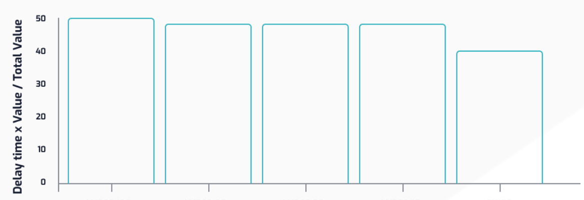
Figure 13: Delay times in CHIPS and reconfigured LVPS2



In LVPS2, settlement cycles take place every two minutes. We performed additional simulations with settlement cycles taking place every 60, 30, and 15 seconds. *Figure 13* shows the average delay time for each of these LVPS2 configurations as well as CHIPS.

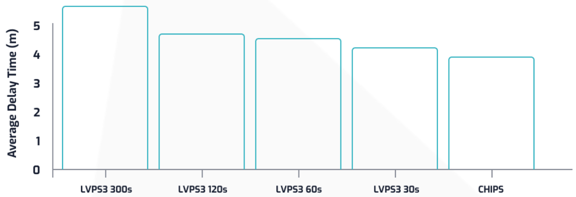
LVPS2 outperformed CHIPS on average delay with the default settlement cycle timing and increasing the frequency of the settlement cycles decreased the average delay time. Payment settlement was nearly twice as fast as in CHIPS when LVPS2 settlement cycles take place every 15 seconds. However, the more frequent settlement cycles had very little impact on weighted delay (see *Figure 14*), with CHIPS outperforming LVPS2 even with 15-second settlement cycles.

Figure 14: Weighted delay in CHIPS and reconfigured LVPS2



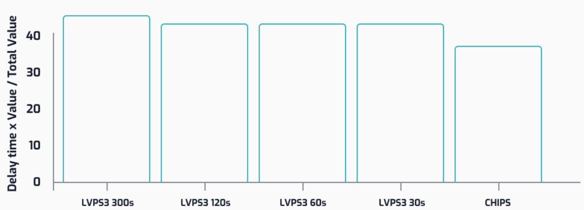
In LVPS3, settlement cycles take place every five minutes. We performed additional simulations with settlement cycles taking place every 120, 60, and 30 seconds. *Figure 15* shows the average delay time for each of these LVPS2 configurations as well as CHIPS.

Figure 15: Delay times in CHIPS and reconfigured LVPS3



As with LVPS2, we see that the average delay time in LVPS3 decreases with each increase in the frequency of settlement cycles. Unlike LVPS2, however, even with settlement cycles at their most frequent, LVPS3 does not settle payments faster than CHIPS. We also see a similar pattern to LVPS2 with weighted delay. Increasing the frequency of settlement cycles beyond every two minutes does not notably improve weighted delay, and LVPS3 does not outperform CHIPS, even with settlement cycles at their most frequent (see *Figure 16)*.

Figure 16: Weighted delay in CHIPS and reconfigured LVPS3



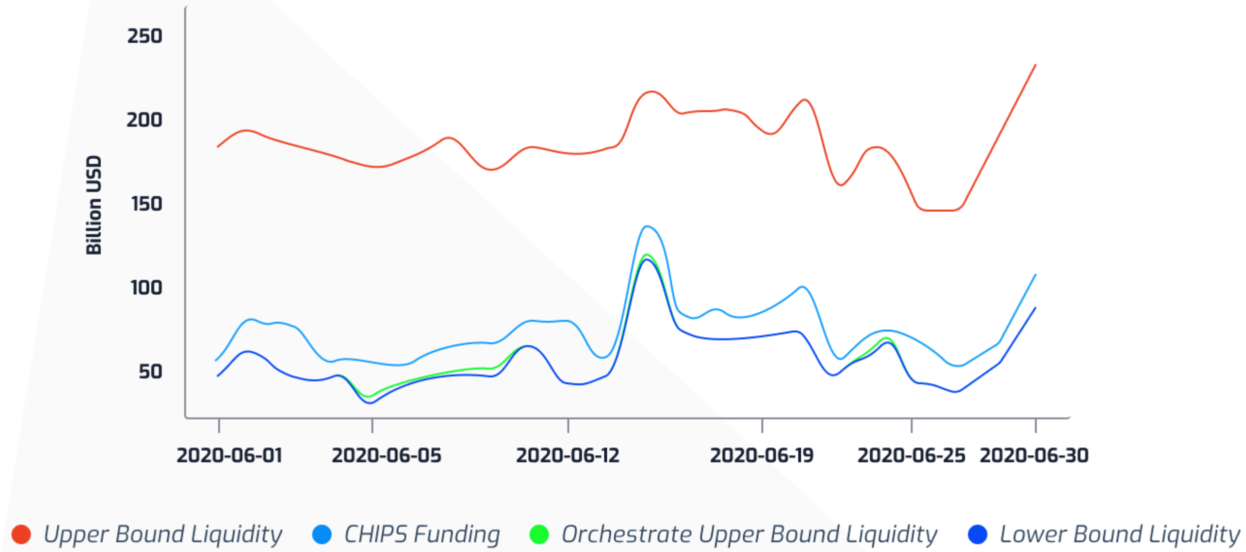
Although LVPS2 settles payments faster than CHIPS, and increasing the frequency of its settlement cycles reduces delay times even further, neither LVPS2 nor LVPS3 outperforms CHIPS on weighted delay, even when increasing the frequency of the settlement cycles. The leveling off of weighted delay seen in *Figures 14* and *16* suggests that even more frequent settlement cycles in these systems are unlikely to result in improved performance on weighted delay.

3.2 Efficiency gains from earlier payment submissions by members

The short delay times in CHIPS suggest that bank carefully manage their internal queues and may wait to submit payments until they can be settled quickly. In this section, we consider queue management at the system level and assume all payments are submitted to CHIPS at the beginning of the day. We use FNA's Orchestrate algorithm, which changes payment settlement order so that payments can be settled using less liquidity, and can lead to reductions in liquidity use close to those seen with multilateral netting (without the need for netting).

To give a brief idea of how this approach could improve performance with CHIPS data, we re-order each day's complete set of payments and then process those payments in a pure RTGS system with unlimited overdrafts to measure the liquidity needed to settle all payments without delay. *Figure 17* shows several measures of liquidity for the June CHIPS payments. Upper bound liquidity is equal to the total liquidity (i.e., funding) needed in the system for all payments to settle gross without delay, and lower bound liquidity is equal to the liquidity needed in the system to settle all payments in a single multilateral netting round. CHIPS funding is equal to the total funding provided to CHIPS each day (equal to the total initial funding plus net supplemental funding, plus total EOD final funding). Orchestrate upper bound liquidity is calculated in the same way as upper bound liquidity, using the CHIPS payments reordered with FNA orchestrate as input. CHIPS funding is 30% higher on average than the minimum funding needed

Figure 17: Measures of liquidity use in CHIPS



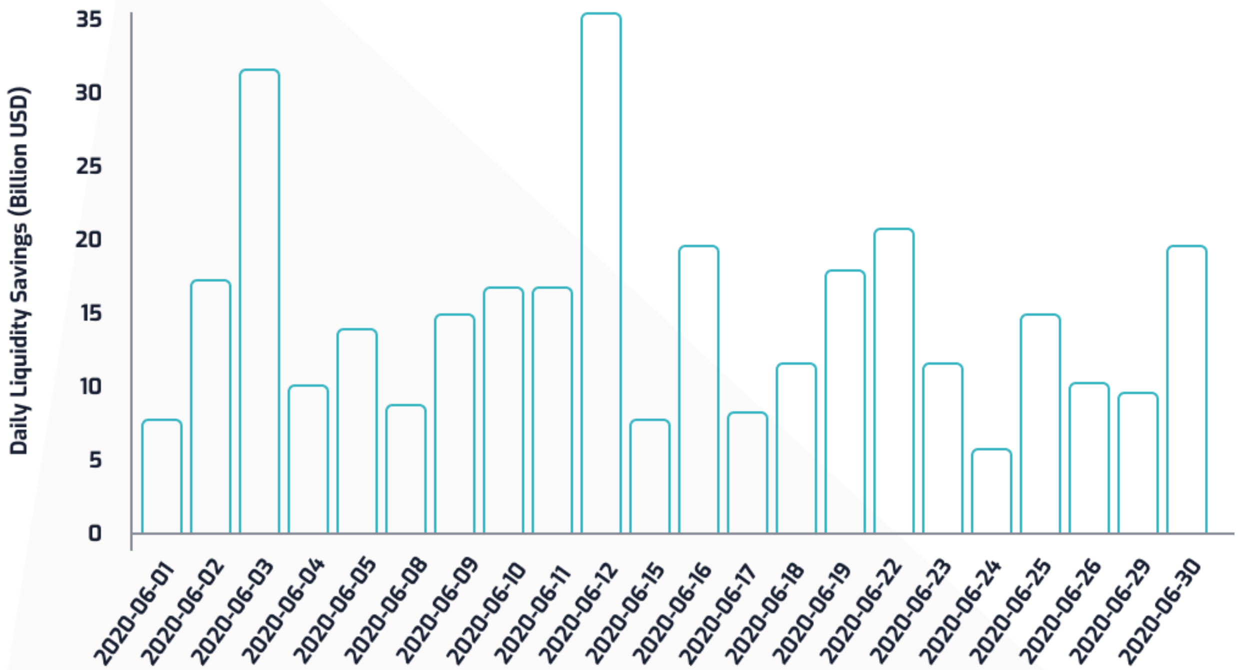
to settle all payments by EOD netting and substantially lower than that required to settle gross all payments without delay. Reordering the payments allows them to settle without delay using only marginally more liquidity (1.4%) than that required to settle all payments by EOD netting. The liquidity needed to settle the reordered payments without delay is on average 22% less than the actual CHIPS funding, for an average savings of $15.1 billion per day.

Figure 18 shows the daily liquidity reduction obtainable by using FNA Orchestrate on each day's complete set of payments (i.e., CHIPS funding minus Orchestrate upper bound liquidity), with liquidity savings ranging from $5.5B to $35.5B.

These results are presented as a proof of concept, as it is unlikely that all payments in the system are known at the beginning of the day. Future research could consider reordering payments during shorter intervals where it is more likely that upcoming outgoing payments are known, e.g., hourly. The reordering methodology might also be used on certain subsets of payments, e.g., large-value payments, to improve the efficiency of settlement algorithms.

Figure 18: Possible liquidity reduction from FNA Orchestrate

Liquidity Savings: CHIPS vs. Orchestrate



4. Conclusions

We have conducted an in-depth simulation study comparing the CHIPS system with several other configurations, including two G7 LVPS, using one month of real CHIPS payments data as input. Although one of the LVPS considered had slightly lower payment delay times than CHIPS, none of the configurations considered uniformly outperformed CHIPS. Importantly, CHIPS outperformed all other configurations on the weighted delay metric, meaning that CHIPS settles higher-value payments faster. CHIPS still outperformed all LVPSs even after substantially increasing the frequency of execution of settlement algorithms in the LVPS. This suggests that it is the efficiency of the CHIPS netting algorithms themselves, rather than their near-constant execution, that is responsible for the effectiveness of the CHIPS system. In particular, the fact that the Doubletree algorithm targets *large* payments helps settle large payments faster. CHIPS also outperformed the other configurations on intraday metrics. The CHIPS system overall, and in particular the settlement algorithms, are extremely efficient and effective.

These results complement those of McAndrews and Vartin (2022), who showed that CHIPS outperforms Fedwire, TARGET2, and CHAPS on several measures of liquidity use when analyzing each system as it is. That is, Fedwire processing Fedwire payments, TARGET2 processing TARGET2 payments, and so on. Here we have shown that CHIPS outperforms several synthetic and actual payment systems for processing CHIPS data. Although we have found the CHIPS system to be extremely efficient, to the point that we were not able to “beat” it with any other system configurations, there may still be some room for improvement.

References

- Bech, M. L. and Soramäki, K. (2001). Gridlock Resolution in Interbank Payment Systems. Bank of Finland Research Discussion Paper No. 9/2001, Available at SSRN: https://ssrn.com/abstract=3018053

- EU (2010). Decision of the European Central Bank of 29 July 2010 on access to and use of certain TARGET2 data. *Official Journal of the European Union*, 451.

- Imakubo, K. and McAndrews, J. (2006). Funding Levels for the New Accounts in the BOJ-NET. Bank of Japan Working Paper Series 06-E-21, Bank of Japan.

- Koponen, R. and Soramäki, K. (1998). Intraday liquidity needs in a modern interbank payment system: A simulation approach. Bank of Finland Simulation Studies E:14.

- McAndrews, J. and Vartin, D. (2022). The Use of Liquidity in CHIPS. The Clearing House Working Paper.

- McLafferty, J. and Denbee, E. (2012). “Liquidity Saving in CHAPS: A Simulation Study”, in B.

- Soramäki, K., Bech, M., Arnold, J., Glass, R., and Beyeler, W. (2007). The topology of interbank payment flows. *Physica A*, 379, 317–333.

- Soramäki K. and Cook, S. (2022). *Network Theory and Financial Risk, 2nd Ed.*, Risk Books: London.