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Payment System Design and Participant Operational Disruptions

Ashwin Clarke and Jennifer Hancock

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Authors: clarkea and hancockj at domain rba.gov.au

Media Office: rbainfo@rba.gov.au

Abstract

Real-time gross settlement (RTGS) systems often incorporate features designed to economise on liquidity. Such 'hybrid features' have the potential to mitigate the systemic impact of operational disruptions of participants. This paper simulates operational disruptions of participants, using data from Australia's RTGS system – the Reserve Bank Information and Transfer System (RITS) – to analyse the effect of these hybrid features on the systemic impact of such disruptions. The results suggest that the bilateral-offset algorithm and sub-limit feature in RITS generally mitigate the impact of a participant's operational disruption, even if there is less liquidity committed to the RTGS system. The hybrid features of the Australian RTGS system also mean that the size of the participant with the operational disruption has less effect on the systemic impact of that disruption than otherwise. While a central queue, in and of itself, would tend to mitigate the impact of a participant's operational disruption, methodological issues make it difficult to draw any conclusions regarding this hybrid feature in this paper.

JEL Classification Numbers: E42, E58, G21

Keywords: large-value payment system, operational disruption, liquidity, simulation

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Payment System Design and Participant Operational Disruptions

Ashwin Clarke and Jennifer Hancock

1. Introduction

High-value payment systems are critical infrastructure for financial markets. To mitigate the systemic impact of a participant's default, most high-value payment systems now settle on a real-time gross settlement (RTGS) basis (Bech, Preisig and Soramäki 2008). But while RTGS eliminates credit risk between participants, it requires more liquidity since payments are settled individually. To limit the call on participants' collateral to secure additional intraday liquidity it is important that liquidity is recycled through the system efficiently. If an operational disruption results in a participant being unable to send payment instructions to the RTGS system for settlement, liquidity accumulates in that participant's account, forming what is known as a 'liquidity sink'. Such a disruption in liquidity recycling can prevent other participants from settling their payments.

The design of RTGS systems varies significantly around the world. Many RTGS systems incorporate elements of net settlement systems to economise on liquidity. Such hybrid features have the potential to mitigate the systemic effect of participants' operational disruptions. Glaser and Haene (2009) suggest that a central queue, which stores transactions that have been submitted to the RTGS system until they can be settled, can reduce the size of the liquidity sink that results from a participant's operational disruption because the payments already queued by that participant can still settle.[1] Liquidity-saving algorithms – such as the bilateral-offset algorithm in Australia's RTGS system, the Reserve Bank Information and Transfer System (RITS) – can also potentially reduce the value of unsettled payments that result from any liquidity shortage caused by a participant's operational disruption. This is because such a feature means that less liquidity is needed to settle payments. Furthermore, features that reserve liquidity for certain types of payments by limiting the liquidity available to settle other types of

1 In contrast, in an RTGS system that does not have a central queue (referred to in this paper as a 'pure' RTGS system), transactions that cannot be settled immediately are rejected and must be resubmitted by the payer institution, and therefore would be affected by an operational disruption at that participant.

payments (such as the ‘sub-limits’ in RITS) tend to slow the flow of liquidity into the liquidity sink, which gives other participants more time to react to the operational disruption.

However, if the liquidity-reservation feature does not specifically target the participant with the operational disruption (i.e. if there are no bilateral limits) it can slow payments between all participants. By restricting the flow of liquidity, broad-based liquidity reservation may increase the value of unsettled payments. In addition, the presence of a liquidity-saving algorithm may result in participants committing less liquidity to the RTGS system, thus negating the benefit that these mechanisms might have during an operational disruption.

This paper analyses the effect of system design on the systemic impact of participant operational disruptions using a simulator developed by the Bank of Finland (‘the simulator’). These simulations use data from Australia’s RTGS system, RITS. As RITS features a central queue with a bilateral-offset algorithm, as well as a sub-limits feature, it provides a rich dataset with which to analyse the effects of system design. The paper also investigates how hybrid features interact with participant reaction times, and how they may alter the relationship between the size of the participant with the operational disruption and the systemic impact of that disruption.

As with all simulation studies, the lack of an endogenous behavioural response means that the results should be interpreted with care. In particular, simplifying assumptions are made regarding different participant behaviours in response to a variation in system design.

The remainder of the paper is structured as follows. Section 2 provides an overview of the literature on system design and operational disruptions. Section 3 describes RITS and its hybrid features. Section 4 presents the methodology used to analyse the effect of system design on operational disruptions in RITS. Section 5 presents the results of the simulation and Section 6 concludes.

2. Literature Review

In recent years there has been a sharp increase in payments settled in hybrid RTGS systems. In 1999, a sample of 22 countries found that 3 per cent of the total value settled in large-value payments systems was settled in RTGS systems that incorporated hybrid features; by 2005 this share had grown to roughly 32 per cent (Bech *et al* 2008).[2] At the same time, hybrid systems have received increased attention in the payments literature, for example: McAndrews and Trundle (2001) and CPSS (2005) provide detailed expositions of hybrid systems; Johnson, McAndrews and Soramäki (2005) and Ercevik and Jackson (2009) use simulation analysis to quantify the impact of introducing hybrid features on liquidity demand and settlement delays; while Martin and McAndrews (2008) and Galbiati and Soramäki (2010) use theoretical models to analyse the impact of hybrid features on participants' incentives.

A separate stream of the payments literature has focused on analysing operational risk in RTGS systems through simulation studies. This literature generally follows the methodology established by Bedford, Millard and Yang (2005) to analyse the systemic effects of simulated operational disruptions that prevent a participant (or multiple participants) from submitting payments. Bedford *et al* simulate operational disruptions in the UK RTGS system, Clearing House Automated Payment System (CHAPS), while Schmitz and Puhr (2007), Andersen and Madsen (2009), Glaser and Haene (2009) and Lublóy and Tanai (2009) perform similar analyses on Austrian, Danish, Swiss and Hungarian RTGS systems, respectively. Results from the simulation analysis vary across studies, with differences largely explained by the level of liquidity in the system under consideration and the size of the participant experiencing the disruption, as well as assumptions about non-stricken participants' reaction to the disruption.

Ledrut (2007) investigates the mitigating effect of participants' reactions by simulating a participant disruption in the Dutch RTGS system. Participants are assumed to react by stopping payments to the stricken participant after a pre-determined time has elapsed or once their exposure to the stricken participant

2 This is based on a study covering 13 countries that were members of the Bank of International Settlements' Committee on Payment and Settlement Systems (CPSS) as at 2005 and 9 non-CPSS euro area countries.

has reached a certain threshold. Ledrut concludes that more timely participant reactions can significantly reduce the systemic consequences of participant-level operational disruptions. Merrouche and Schanz (2009) also investigate counterparties' reactions to a participant's operational disruption. Based on an econometric model of CHAPS, they find that payment flows to stricken participants tend to decrease until around one hour into the disruption, but increase slightly afterwards, presumably as the cost of violating contract obligations or market practices by delaying payment increases.

3. Australia's RTGS System

RITS has operated as an RTGS system since 1998.[3] Over 90 per cent of interbank settlements, by value, in Australia are settled on a gross basis through RITS; this share has been broadly steady since RITS commenced operations.[4] In 2011, RITS settled on average around 35 500 transactions each day, with an average total value of $171 billion, using around $16 billion of liquidity. Liquidity in RITS is sourced from overnight balances held in participants' accounts at the Reserve Bank of Australia (RBA) and additional funds made available to participants by the RBA via interest-free intraday repurchase agreements (repos). Access to these funds is limited only by participants' holdings of eligible securities. In the sample period, RITS had 59 direct participants, although the system is quite concentrated; the 4 major Australian banks are counterparts to almost 60 per cent of transactions settled through RITS.

The central queue in RITS operates on a 'bypass first-in first-out (FIFO) basis'.[5] If the transaction being tested for settlement cannot be settled individually, the bilateral-offset algorithm searches for up to 10 offsetting transactions (based on the order of submission), which it attempts to settle simultaneously.[6] RITS participants

3 For more information on RTGS in Australia see Gallagher, Gauntlett and Sunner (2010).
4 The remaining 10 per cent of interbank settlements in RITS are settled in deferred net batches.
5 Payments are tested for settlement in the order of submission, but rather than stopping if the first payment cannot be settled immediately, the system moves on to test the next payment in the queue for settlement, and so on, looping back to the first payment when it reaches the end of the queue.
6 In July 2009, the RBA added a 'targeted' bilateral-offset algorithm, which allows participants to select specific payments for bilateral offset.

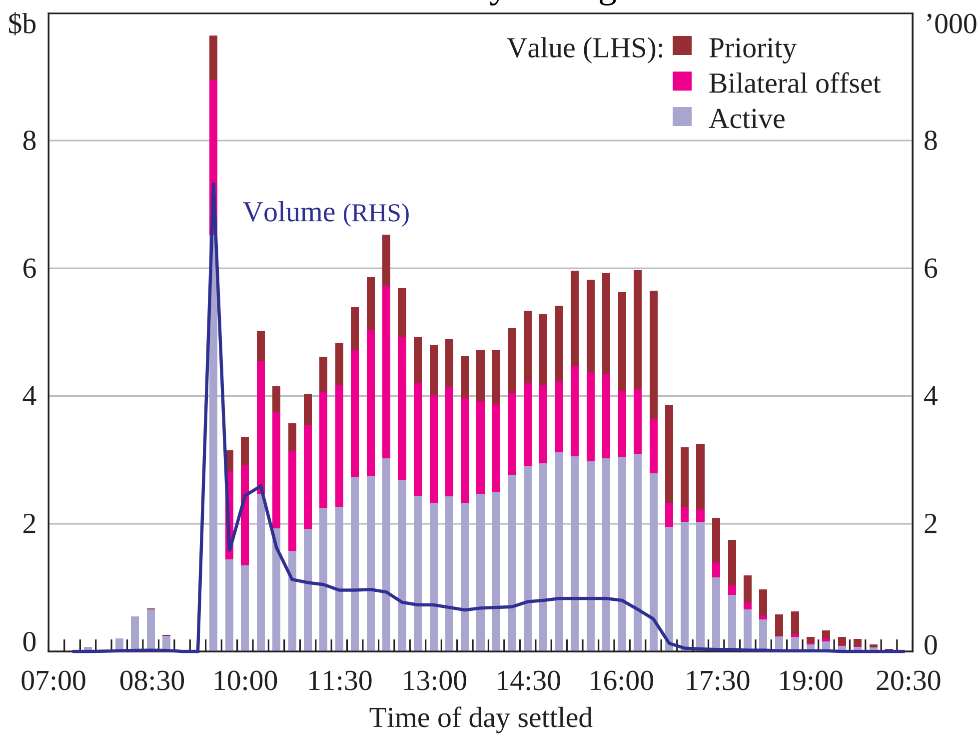
have access to real-time information, including their settled and queued payments and receipts. RITS incorporates a sub-limit feature that assists participants in managing their payments by allowing them to reserve liquidity for 'priority' payments. Balances below the sub-limit set by participants are reserved for settlement of 'priority' transactions. In contrast, 'active' payments are only tested for settlement against balances in excess of the sub-limit. 'Deferred' payments are not tested for settlement until the sending participant changes the status of the payment to either active or priority, which can be done at any time prior to settlement.

Approximately 30 per cent of the value of RITS payments settled in 2011 were settled by means of a bilateral offset, while just under 20 per cent were settled as priority payments, using liquidity protected by sub-limits (Figure 1). A quarter of the value of payments in RITS is settled between 3.00 pm and 5.00 pm, during which time around 40 per cent of priority payments are made. In contrast, RITS volumes are concentrated at the beginning of the day, with a large number of small payments settling around 9.15 am, which is immediately after the opening of the main RTGS settlement session.[7]

7 RITS opens at 7.30 am but RTGS payments on behalf of customers are only eligible for settlement after 9.15 am.

Figure 1: Use of Hybrid Features in RITS

2011 daily average



Source: RBA

4. Methodology

4.1 The Simulator

The Bank of Finland has developed a versatile Payment and Settlement System Simulator (BoF-PSS2) for modelling the complex interactions that occur in payment and settlement systems. Simulations can be used for analysing the implications for liquidity and risk of changes in system functionality, market structure, and settlement rules or conventions, as well as the effect of specific events (such as a participant’s operational disruption). Broadly, the Bank of Finland simulator mimics the functionality of RTGS systems; it requires the user to input transaction, liquidity and other data, which are then processed according to specified algorithms that simulate the workings of an actual RTGS system. The simulations generate a wide range of transaction-level and aggregated data, such as the time that each transaction was settled and the value of unsettled payments at the end of a day.

4.2 Data

Our simulations are based on RITS transaction, liquidity and sub-limit data from 10 business days in the first quarter of 2008. This period is representative of a typical fortnight in 2008. During this period there was an average of $191 billion settled each day using around $15 billion of liquidity (i.e. each dollar was used to make an average of 13 payments each day), compared with a daily average of $195 billion using around $17 billion in 2008 as a whole. The value of payments settled on a particular day in our sample ranges from $96 billion to $247 billion, with a sample standard deviation of $41 billion, compared with a standard deviation of $38 billion for 2008 as a whole.

4.3 System Design

To measure the marginal benefit of hybrid features during an operational disruption, participant-level disruptions are simulated under five different system designs (Table 1). Since hybrid features usually require a central queue, all system designs, other than the pure RTGS system, incorporate this feature. Like RITS, the RITS replica has a combination of a central queue, a bilateral-offset algorithm and sub-limits. To roughly disentangle the effects of sub-limits and bilateral offset, a system with only sub-limits and a system with only bilateral offset are examined. Rather than using the existing algorithms in the simulator, this paper uses modified algorithms that more closely match the bilateral-offset algorithm and sub-limit features in RITS (see Appendix A for further details).

Table 1: System Designs

	Central queue	Bilateral offset	Sub-limits
Pure RTGS	–	–	–
Central queue only	✓	–	–
Bilateral offset	✓	✓	–
Sub-limits	✓	–	✓
RITS replica	✓	✓	✓

4.3.1 Submission times

While a change in system design is likely to provide an incentive for participants to vary submission times, for simplicity this paper generally assumes that there is no change in submission behaviour.[8] However, since there is no central queue to coordinate payments in a pure RTGS system, participants require some internal mechanism to ensure that a payment is only sent to the RTGS system when the participant has sufficient funds to settle that payment. Consequently, RITS submission times are unlikely to be appropriate when simulating a pure RTGS system. Instead, settlement times from the benchmark simulations of the central-queue-only system are used to proxy the submission times in the pure RTGS system.[9] As a result, the key difference between the pure RTGS and central-queue-only simulations is the payments on the queue. This set-up is likely to underestimate the benefits of a central queue since the visibility of queued receipts on a central queue can decrease participants' uncertainty regarding their future liquidity requirements and thereby reduce their incentive to delay submitting payments.[10]

The assumptions regarding submission time are also likely to understate the benefit of a bilateral-offset algorithm and sub-limit functionality, since inclusion of each of these features provides an incentive to submit payments earlier. A bilateral-offset algorithm reduces the incentive to submit payments late by potentially lowering the amount of liquidity required to settle payments, especially in combination with sub-limits that allow participants to reserve liquidity for time-critical payments.

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8 The submission times and status of payments that experience status changes between submission and settlement in RITS have been amended to best replicate when these payments settle, as the option to change payment status is not available in the simulator. See Appendix A for further details.

9 In addition, as simulations cannot incorporate the re-submission of payments that do not settle immediately in a pure RTGS system, the central queue model (with adjusted submission times) is used to simulate the pure RTGS system. Payments that do not settle immediately are queued and re-tested for settlement at a later stage, as if they had been re-submitted.

10 RITS provides each participant with real-time information on their queued payments and receipts. In order to prevent participants incurring credit risk by crediting their customers before interbank settlement has occurred, the receiving participant does not receive details of the ultimate beneficiary until the payment has settled, although the paying and receiving participant are identified.

4.3.2 Liquidity

As noted above, participants may decrease their holdings of liquidity in response to the inclusion of liquidity-saving algorithms, thus potentially negating the benefit of such features in the event of an operational disruption. Consequently, we report results based on actual liquidity from RITS and assume that participants decrease their holdings of liquidity by 30 per cent in response to the presence of the bilateral-offset algorithm.[11] For the latter simulations, participants' actual shares of liquidity are maintained, as this should be a reasonable indicator of each participant's relative access to liquidity.

A 30 per cent reduction in liquidity was selected after analysing the effect of varying available liquidity on the value of unsettled payments in each of the four system designs with a central queue (Figure 2). As expected, the bilateral-offset algorithm significantly decreases the liquidity required to settle payments. However, an extremely large increase in liquidity would be required to settle all payments in systems that do not incorporate the bilateral-offset algorithm. Consequently, liquidity in the RITS replica and bilateral-offset systems is scaled down by 30 per cent to equalise the value of unsettled payments across all system designs at around $1.5 billion.

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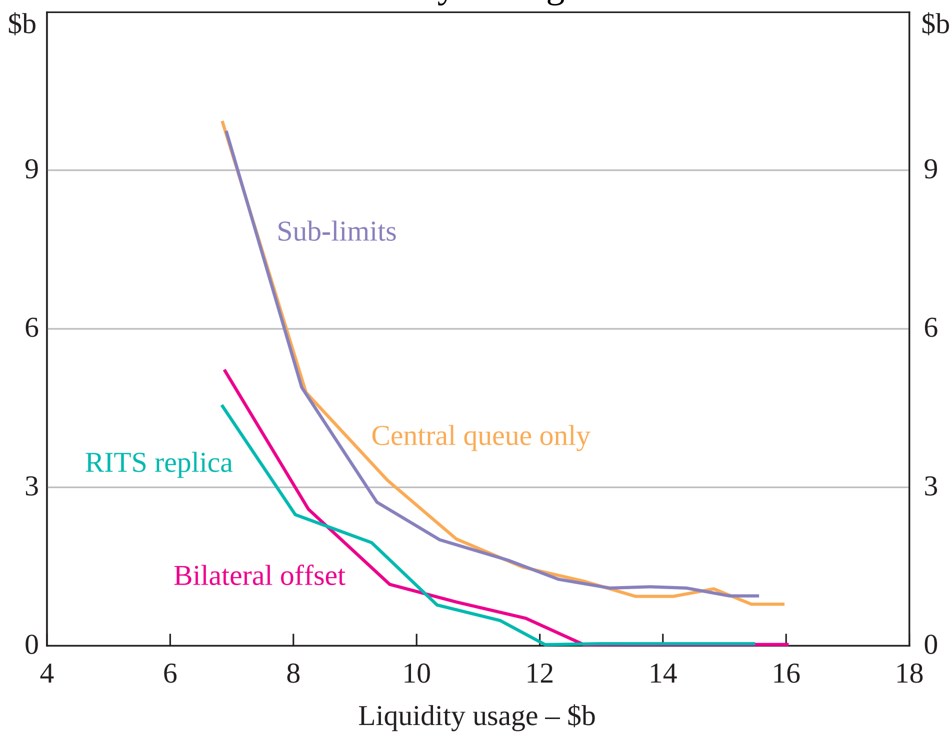
11 In the 'actual liquidity' simulations, we assume that participants do not unwind intraday repos until the end of the day to minimise the effects of changes in the timing of settlement in the simulations. This is a reasonable assumption if the main driver of the cost of liquidity is the maximum value of collateral used, rather than the length of time during the day that the securities are used. For simplicity, we allow unlimited liquidity for the RBA, CLS Bank and the settlement accounts of the equity and futures clearing and settlement systems.

Figure 2: Unsettled Payments

Daily average



4.3.3 Sub-limits

In general, observed behaviour in RITS (i.e. sub-limits and payment status) is replicated when simulating systems with sub-limit functionality. However, it is reasonable to assume that participants will use all available liquidity to settle any payments outstanding at the end of the day; therefore sub-limits are reduced to zero shortly before the system closes to allow as many payments to settle as possible.

4.4 Measuring the Effect of a Disruption

The primary statistic used to measure the impact of an operational disruption is the average total value of unsettled payments each day.[12] Given that the focus is on the systemic impact of a disruption, the measure of unsettled payments excludes

12 The impact of an operational disruption could have been measured in an equivalent fashion using the value of additional liquidity required to settle all transactions. Another measure of the systemic impact is the simulator's settlement delay indicator.

payments to or from the stricken participant.[13] In addition, the value of the liquidity sink, measured as the stricken participant's end-of-day balance after repaying any intraday repos, is reported.

4.5 Simulation Scenarios

In analysing the interaction between system design and participant reaction time, this paper follows the methodology used by Glaser and Haene (2009), who build on the approach established by Bedford *et al* (2005), to find the time when the largest 'theoretical liquidity sink' will form in RITS.[14] The theoretical liquidity sink is defined as follows:

$$Theoretical\ Liquidity\ Sink_{it} = Balance_{it} + \sum_{t}^{t+R} Receipts_{it} - Value\ on\ Queue_{it} \qquad (1)$$

where i is the stricken participant, $Balance_{it}$ is participant i's balance at the central bank at time t, $Receipts_{it}$ is the value of receipts it is due, $Value\ on\ Queue_{it}$ is the value of its outgoing payments on the queue and R represents the time it takes non-stricken participants to react. When identifying the largest theoretical liquidity sink, it is assumed that non-stricken participants take two hours to react to the operational disruption and that the disruption to participant i's payments lasts until the end of the day.

Since system design affects exactly when payments settle, the simulation starts from the point of the disruption to ensure that the results across systems are comparable. As a result, for any given day simulated, the same payments are outstanding at the start of the simulation, regardless of the system design. Benchmark simulations, in which there is no operational incident, are run for each day using each system design in order to allow unsettled payments resulting from the changes in system design to be identified; this results in five scenarios, one each for the five types of system design under consideration.

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13 Note that changing the system design (without an endogenous response to this by participants) can result in unsettled payments due to insufficient liquidity, even without simulating a participant operational disruption. As a result, the value of unsettled payments, particularly in systems without bilateral offset, may be slightly overstated.

14 In common with Bedford *et al*, the largest theoretical liquidity sink is restricted to the morning to ensure that there is a significant value of payments to settle after the disruption.

An operational disruption, at the participant and time identified using the method above, is then simulated with three different reaction times – participants reacting by stopping payments to the stricken participant after 10 minutes or 2 hours, or not reacting at all.[15] These three reaction times are modelled for each of the five system designs, with scenarios covering all relevant combinations of assumptions (Table 2). For the pure RTGS and central-queue-only systems, the only relevant assumption is the reaction time, as these systems do not include sub-limits or bilateral offset, therefore three scenarios are modelled for each of these two systems.

Table 2: Reaction Time Scenarios

System design	Reaction time	Liquidity	Sub-limits	Number of scenarios
Pure RTGS	3	na	na	3
Central queue only	3	na	na	3
Bilateral offset	3	2	na	6
Sub-limits	10 minutes	na	2	2
	2 hours	na	2	2
	No reaction	na	na	1
RITS replica	10 minutes	2	2	4
	2 hours	2	2	4
	No reaction	2	na	2

The liquidity assumption is relevant to systems that incorporate the bilateral-offset algorithm. Consequently, in the RTGS system with bilateral offset the three reaction times are simulated using both actual liquidity and a 30 per cent reduction in liquidity. This results in six scenarios being simulated (i.e. three reaction times x two liquidity assumptions).

In systems with sub-limits, two additional reactions to the disruption are considered. In the first case, it is assumed that participants react by not only stopping payments to the stricken participant, but also by dropping their sub-limits to zero to maximise the liquidity available to settle payments between non-stricken participants. In the second, it is assumed that participants do not drop their sub-

15 Due to technical limitations, we are unable to prevent priority payments submitted before the time at which participants react from settling.

limits. As the sub-limit assumption is irrelevant if there is no reaction, this means that five scenarios are simulated using the RTGS system with sub-limits for each day in the sample period.

For the RITS replica system, all three assumptions are relevant. For the 10-minute and 2-hour reaction times, both liquidity and sub-limit assumptions are modelled, resulting in four scenarios for each of these two reaction times. When it is assumed that participants do not react, only the two liquidity assumptions are relevant, resulting in a further two RITS replica scenarios.

In addition, this paper also investigates how system design affects the relationship between the size of the participant experiencing the operational disruption and the systemic effects of that disruption. This involves conducting a further set of simulations for the largest 15 participants (measured by value of payments submitted and received).[16] These simulations use a 2-hour reaction time, as anecdotal evidence suggests that this is the approximate time it takes participants in RITS to react to an operational disruption. As the value of queued payments varies at different times of day, disruptions at 9.15 am, 12.00 pm and 3.00 pm are modelled in these participant-size scenarios. Varying the time of day, the participant affected and the system design requires running 225 different scenarios for each day simulated (i.e. 3 times x 15 participants x 5 system designs).

5. Results

5.1 System Design and Reaction Times

5.1.1 Actual liquidity

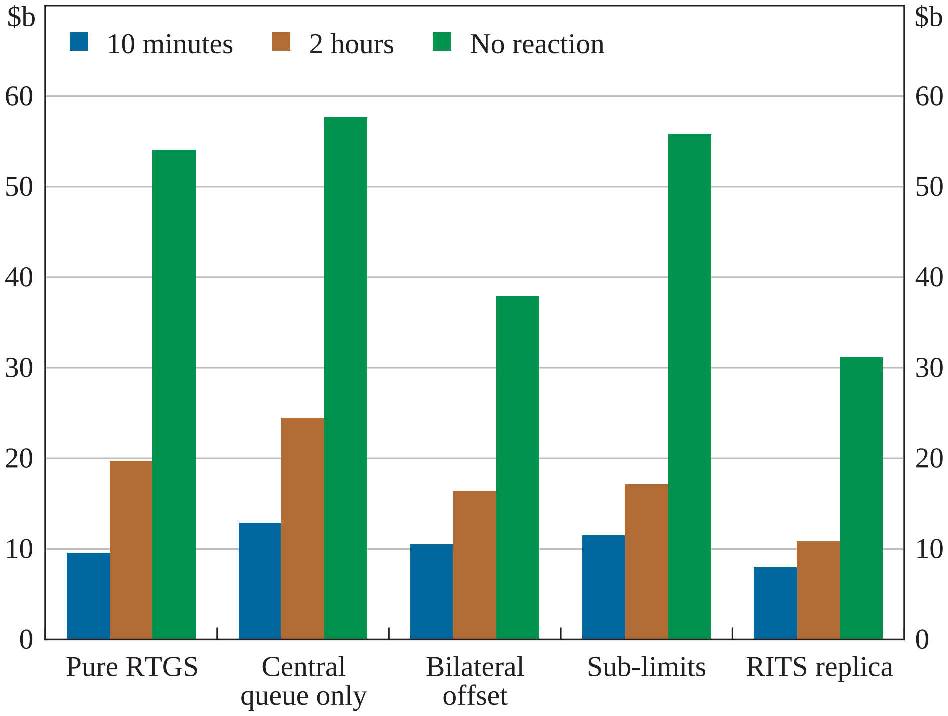
Our results confirm Ledrut's (2007) finding that slower participant reaction times increase the effect of operational disruptions. In other words, the longer the time taken to stop payments to the participant with the disruption (i.e. the reaction time), the higher the average value of unsettled payments between non-stricken participants (Figure 3). If participants do not react, the daily average proportion of

16 Excluding the RBA, CLS Bank and the settlement accounts for the equity and futures markets.

unsettled payments is over 40 per cent of the total value of payments between non-stricken participants in systems without bilateral offset. In contrast, the daily average proportion of unsettled payments when participants react 10 minutes after the disruption ranges from 8 per cent to 12 per cent, depending on the system design.

Figure 3: Unsettled Payments

Actual liquidity, daily average



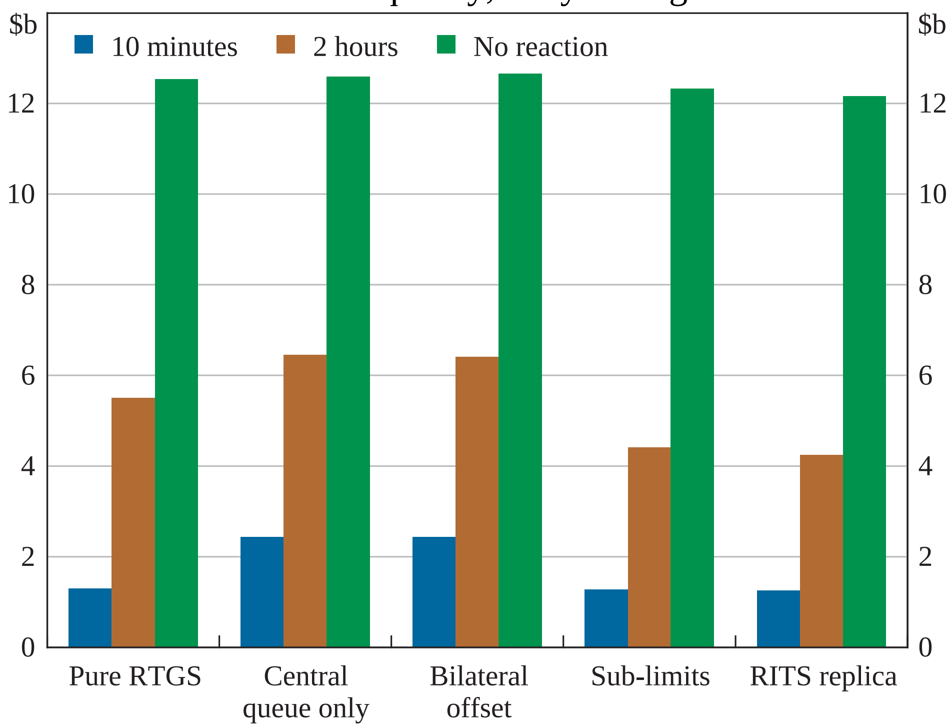
While the results suggest that introducing a central queue, in and of itself, does not mitigate the systemic effect of participant operational disruptions – in fact, the systemic impact is slightly larger moving from the pure RTGS to the central-queue-only design – this is probably due to methodological issues.[17]

17 A central queue is expected to mitigate the systemic effect of a participant's operational disruption because the queued transactions from the stricken participant can continue to settle after the operational disruption occurs, thus reducing the size of the liquidity sink. However, the method used in this paper to select the disruption is likely to understate the benefit of a central queue. Since queued payments from a participant decrease the size of the theoretical liquidity sink, the largest theoretical liquidity sink is likely to occur when there are minimal queued payments from the stricken participant. Thus is it not unexpected that there is very little difference between our results for the central queue and pure RTGS systems.

Not surprisingly, use of the bilateral-offset algorithm reduces the systemic impact of participant operational disruptions. Compared to the central-queue-only system, the daily average proportion of unsettled payments in the bilateral-offset system decreases by between 2 and 14 percentage points, depending on the participant reaction time. The results also suggest that a quick reaction by other participants is less important in systems with bilateral offset. However, bilateral offset does not have a noticeable impact on the size of the liquidity sink (Figure 4). The caveat to these results, which is investigated further in the following sub-section, is that participants may respond to the inclusion of a bilateral-offset algorithm by decreasing the amount of liquidity they hold, which may overstate the benefit of having such an algorithm.

Figure 4: Liquidity Sinks

Actual liquidity, daily average



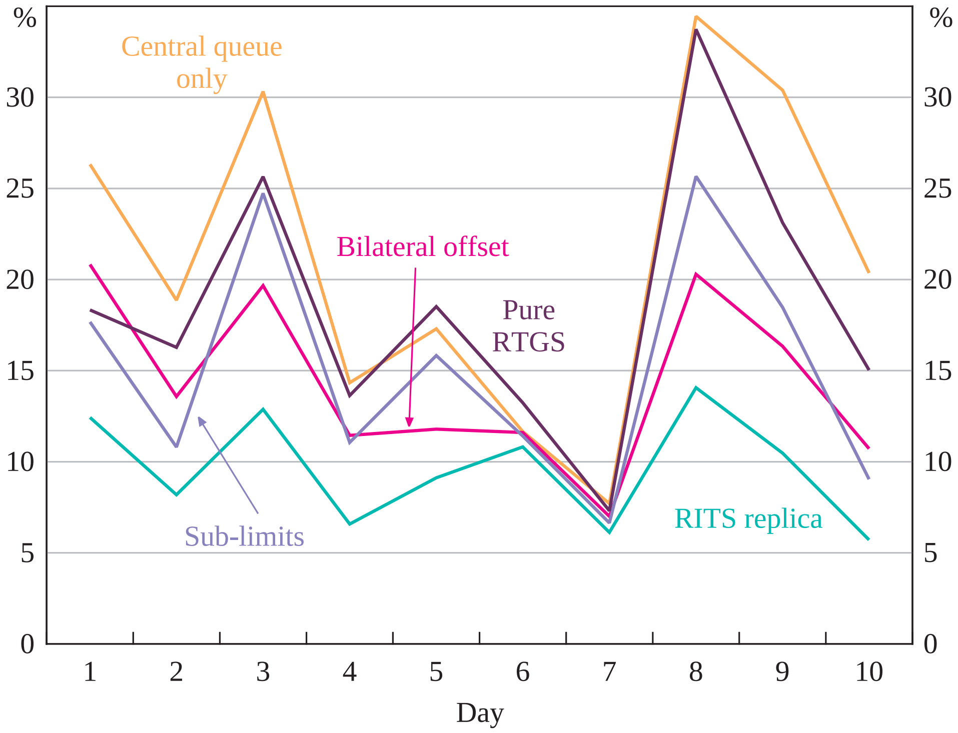
As noted in the introduction, the sub-limit feature slows liquidity recycling, which could increase or decrease the systemic impact of a participant operational disruption. The net effect of sub-limits depends on participants' reaction times; as long as participants stop payments to the stricken participant and lower their sub-limits within 2 hours, sub-limits mitigate the effect of a longer reaction time. For example, for a 2-hour reaction time, the daily average proportion of unsettled payments in the sub-limits system is 6 percentage points lower and the liquidity sink is $2.0 billion smaller than in the central-queue-only system. If participants only react at the end of the day, sub-limits slow the development of the liquidity sink without increasing the liquidity available to settle payments between non-stricken participants. As a result, when sub-limits are dropped at the end of the day, the remaining queued payments to the stricken participant settle and the size of the liquidity sink is much the same as it is for systems in which there are no sub-limits.

In our simulations, the systemic consequences of an operational disruption, across all the reaction times, are minimised by the combination of sub-limits and bilateral offset in the RITS replica system. Specifically, if participants react after 2 hours, the daily average proportion of unsettled payments in the RITS replica system are reduced by a further 5 percentage points, on top of the 7 percentage point reduction from introducing the bilateral-offset algorithm. Similarly, for a 10-minute reaction time, the average proportion of unsettled payments is reduced by a further 2 percentage points on top of the 2 percentage point reduction when bilateral offset is introduced.

Inter-day variation in the proportion of unsettled payments is also lower in systems with bilateral offset and sub-limits (Figure 5). On days such as day seven of our data sample, when participants committed a relatively large amount of liquidity to the system, the system design has minimal effect on the impact of the systemic disruption. However, the proportion of unsettled payments is more stable for the RITS replica system across all ten days in the sample, ranging between 6 and 14 per cent.

Figure 5: Unsettled Payments

As a proportion of value submitted, 2-hour reaction time

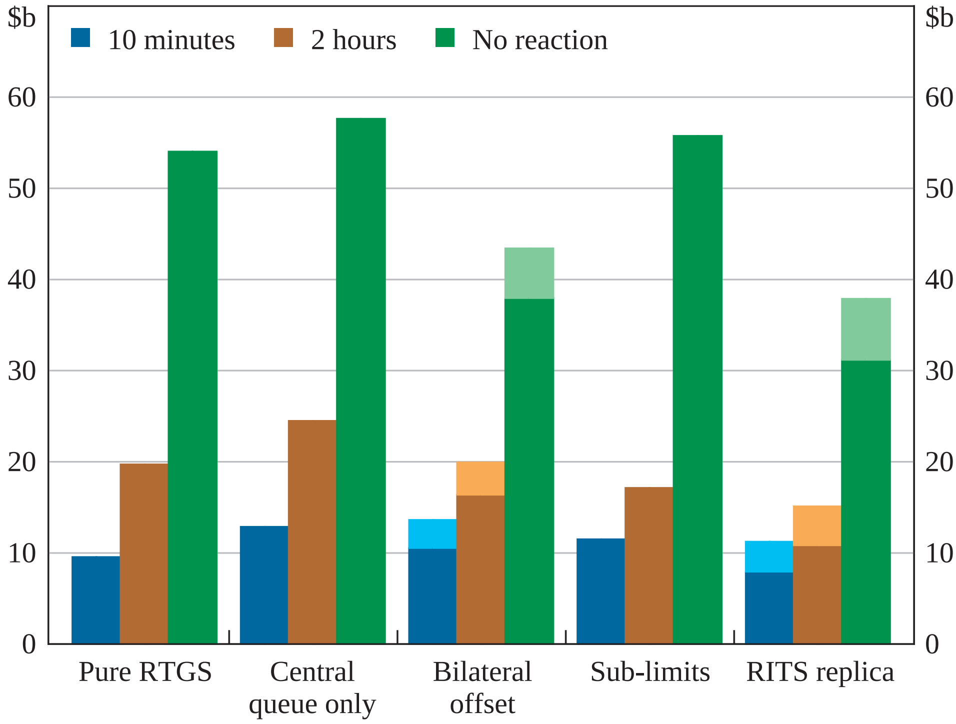


5.1.2 Scaled liquidity

The results from the simulations in which the liquidity available in the systems that include a bilateral-offset algorithm is reduced by 30 per cent are as follows. In this case, the daily average proportion of unsettled payments in the bilateral-offset system increase by between 2.9 percentage points and 4.5 percentage points (the lighter shaded segments in Figure 6). With a 10-minute reaction time, the decrease in liquidity negates the liquidity-saving benefit of the bilateral-offset algorithm when compared with the central-queue-only system. While the inclusion of a bilateral-offset algorithm does mitigate the systemic impact of a disruption when participants react after 2 hours, the reduction in liquidity means that the bilateral-offset algorithm, by itself, is less effective than sub-limits on their own (as long as participants do react).

Figure 6: Unsettled Payments

Liquidity scaled, daily average



Note: The lighter shaded segments of the columns represent the additional unsettled payments resulting from the 30 per cent reduction in liquidity in the systems with bilateral offset

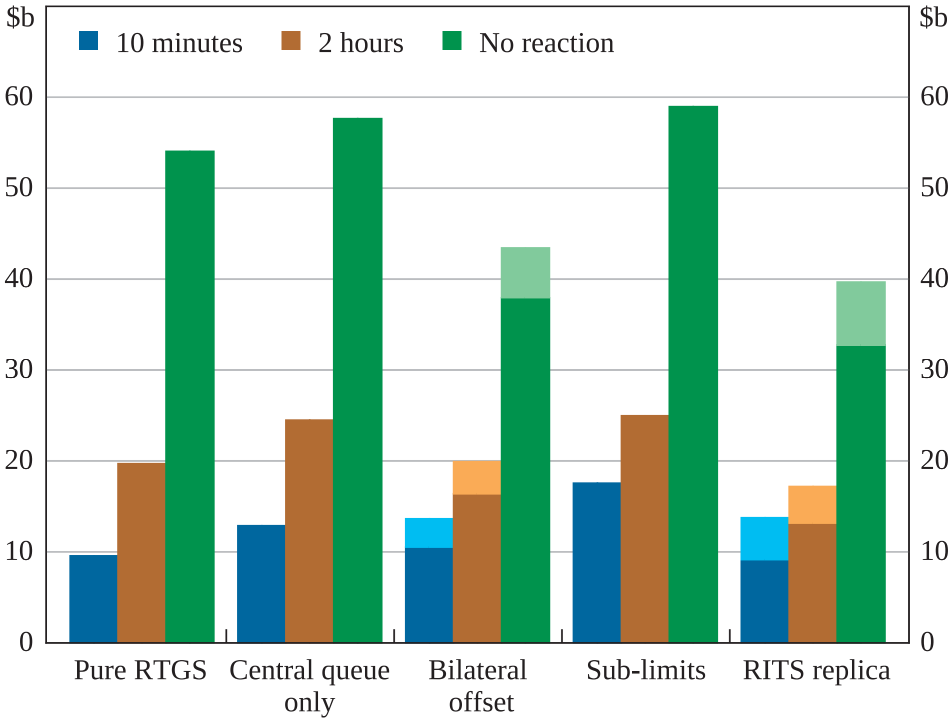
Even when participants hold less liquidity, the RITS replica system remains the most effective system for minimising the systemic impact of a participant's operational disruption. A 30 per cent reduction in liquidity causes the average proportion of unsettled payments in the RITS replica system to increase by between 3 percentage points (for the 10-minute reaction time) and 5 percentage points (for the no reaction scenario).

5.1.3 Sub-limits maintained

If non-stricken participants choose to maintain their sub-limits when they react to the operational disruption, the daily average proportion of unsettled payments in the sub-limit-only system increases by between 2 and 7 percentage points (relative to the equivalent scenario in which participants chose to lower their sub-limits when they react to the operational disruption) (Figure 7). This is because liquidity trapped by the sub-limits is not recycled. Similarly, as a result of maintaining sub-limits the daily average proportion of unsettled payments in the RITS replica system also increases by a couple of percentage points. Nevertheless, for a given reaction time and level of liquidity, unsettled payments are still generally lowest in the RITS replica system.

Figure 7: Unsettled Payments

Liquidity scaled, sub-limits unchanged, daily average



Note: The lighter shaded segments of the columns represent the additional unsettled payments resulting from the 30 per cent reduction in liquidity in the systems with bilateral offset

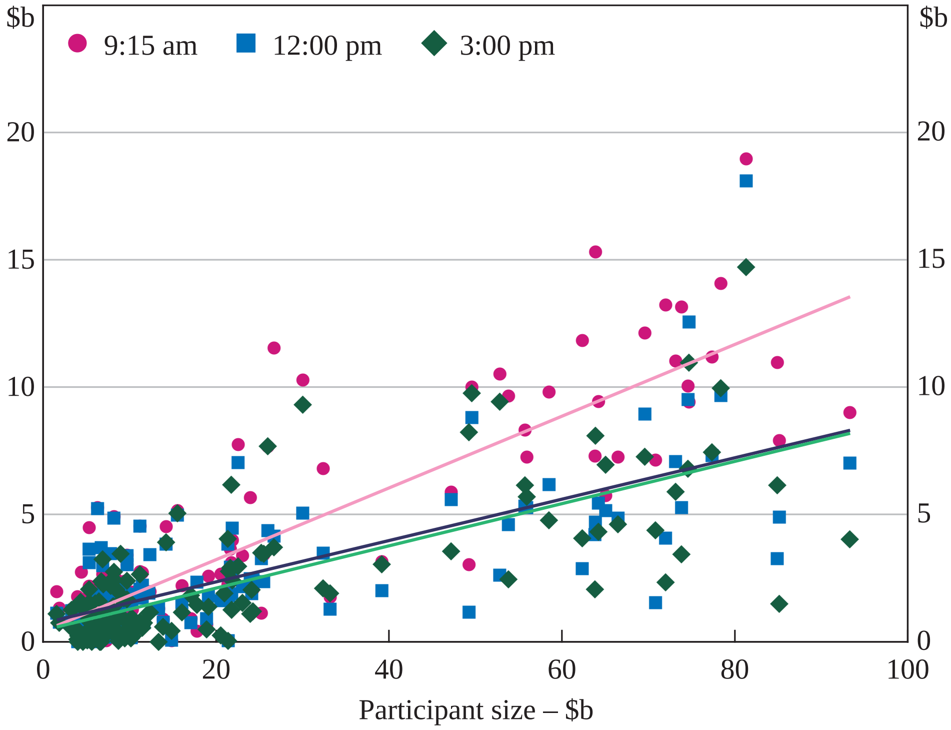
5.2 System Design and Participant Size

It seems likely that the larger the participant (measured in terms of the value of a participant's payments and receipts) experiencing the operational disruption, the larger the systemic effects of that disruption. However, this may oversimplify the issue of size, since the timing of the disruption and the stricken participant's liquidity- and queue-management behaviour also affect the systemic impact of the disruption.

To examine this, operational disruptions at the largest 15 participants are simulated assuming a 2-hour reaction time. The results show that the impact of an operational disruption varies depending on when the disruption is assumed to have occurred. Figure 8 shows, for the RITS replica system, the relationship between the size of the stricken participant (measured as the total value of payments submitted to the system on the specific day to which it was a counterparty) and the systemic impact (measured as the value of unsettled payments) for operational disruption occurring at 9.15 am, 12.00 pm or 3.00 pm. As indicated by the line of best fit, the value of unsettled payments tends to be greatest when the disruption starts at the beginning of the day. The midday disruptions generally have a similar impact to the afternoon disruptions. This ordering broadly holds across all system designs simulated. This is not too surprising since there are more payments yet-to-be settled when a disruption occurs earlier in the day.

Figure 8: Unsettled Payments

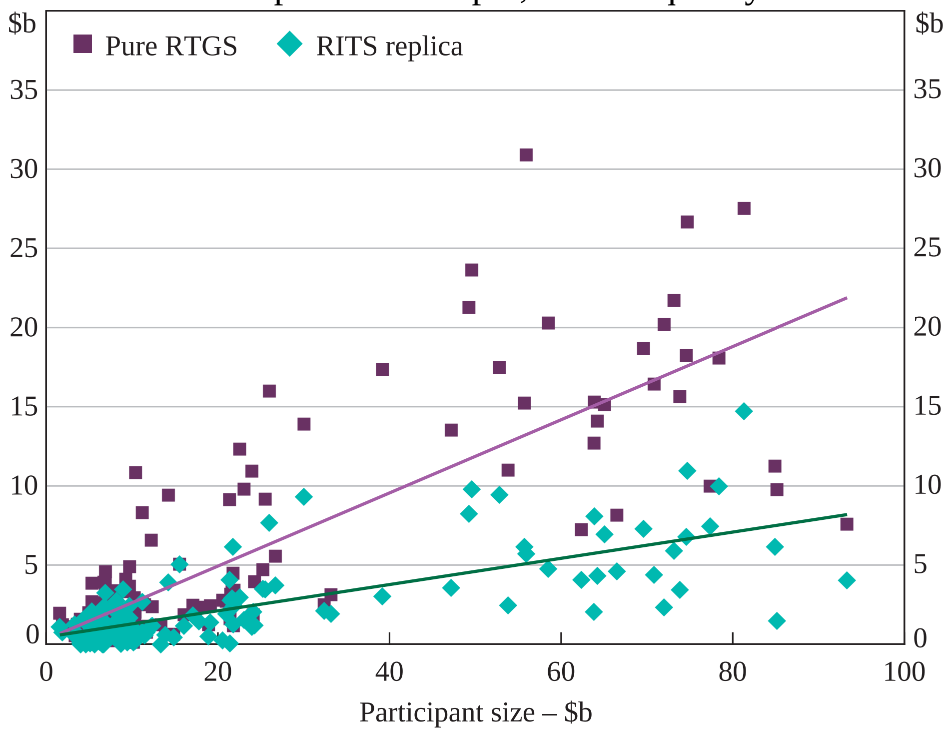
RITS replica, actual liquidity



Our results also show that the inclusion of hybrid features reduces the systemic impact of an operational disruption for a participant of a given size. For example, as indicated by the line of best fit in Figure 9, for a given participant size, the value of unsettled payments is lower in the RITS replica system than the pure RTGS system.

Figure 9: Unsettled Payments

Disruption at 3:00 pm, actual liquidity



Some more detailed analysis of individual results underscores the importance of participants' liquidity- and queue-management strategies. In general, when the stricken participant tends to submit payments earlier than its peers, and the operational disruption occurs later in the day, the systemic impact of a disruption is smaller.

6. Conclusion

The results of simulations conducted in this paper suggest that the systemic impact of operational disruptions of participants is generally mitigated by the inclusion of hybrid features in an RTGS system. The bilateral-offset algorithm, combined with sub-limits, is the most effective way to mitigate the systemic consequences of an operational disruption. While the inclusion of a bilateral-offset algorithm lowers the value of unsettled payments resulting from an operational disruption, the extent of this beneficial effect is reduced if participants respond to this hybrid feature by reducing their holdings of liquidity. Sub-limits can also reduce the systemic impact of an operational disruption, as long as participants react to the disruption by stopping payments to the stricken participant and lowering their sub-limits to zero.

Methodological issues make it difficult to come to any firm conclusions regarding the benefits of introducing a central queue, in and of itself.

Simulated disruptions for the largest 15 participants of RITS also demonstrate that hybrid features tend to mitigate the effect of participant size on the systemic impact of a disruption at that participant.

When interpreting the results of this paper, the potential effect of endogenous behavioural responses (which are beyond the scope of this paper) need to be considered. In particular, the assumptions made in the simulations are likely to understate the benefits of incorporating hybrid features to the extent that these features encourage earlier submission of payments. A logical extension to this work would be to incorporate expected differences in submission behaviour relating to differences in the design of a system. This is left to future work.

Appendix A: Simulator Algorithms

The algorithms in the Bank of Finland simulator were modified to broadly replicate the hybrid features in RITS. In particular, we modified the bilateral-offset algorithm to test all queued transactions. Our algorithm tests each queued transaction against a maximum of ten offsetting transactions, starting with the first queued offsetting transaction and adding, in FIFO order, up to nine further offsetting transactions. Applying this algorithm, 27 per cent of the total value of settlements is settled via bilateral offset, which is close to the actual share of payments (25 per cent) settled via bilateral offset in RITS. This compares with around 5 to 10 per cent using the unmodified algorithm (which only tests for simultaneous settlement of transactions between the counterparties of the first queued transaction). The remaining difference between the bilateral-offset algorithm constructed for the purposes of the simulation and the RITS functionality is that for the former, payments are only tested for bilateral offset once all payments have been tested for individual settlement. In contrast, RITS first tests each payment for individual settlement and then checks whether a bilateral offset is possible (as long as the payment has been queued for at least a minute), before moving on to the next payment (Figure A1).

In the simulator, the entry, queue and bilateral-offset algorithms have been modified to broadly match RITS' sub-limit functionality. Based on a payment's status these algorithms adjust the amount of liquidity available to settle that payment based on the sub-limit data, which is entered using the bilateral limits input table. Given the inability to allow for changes to payment status in the simulations, as well as a lack of data on precisely what time these changes occurred, the rules of thumb used to determine a payment's status and the submission time are as shown in Table A1. These are based on when the status was most likely to have changed.[18]

18 Payment status is discussed in greater detail in Section 3.

Figure A1: RITS Settlement Tests

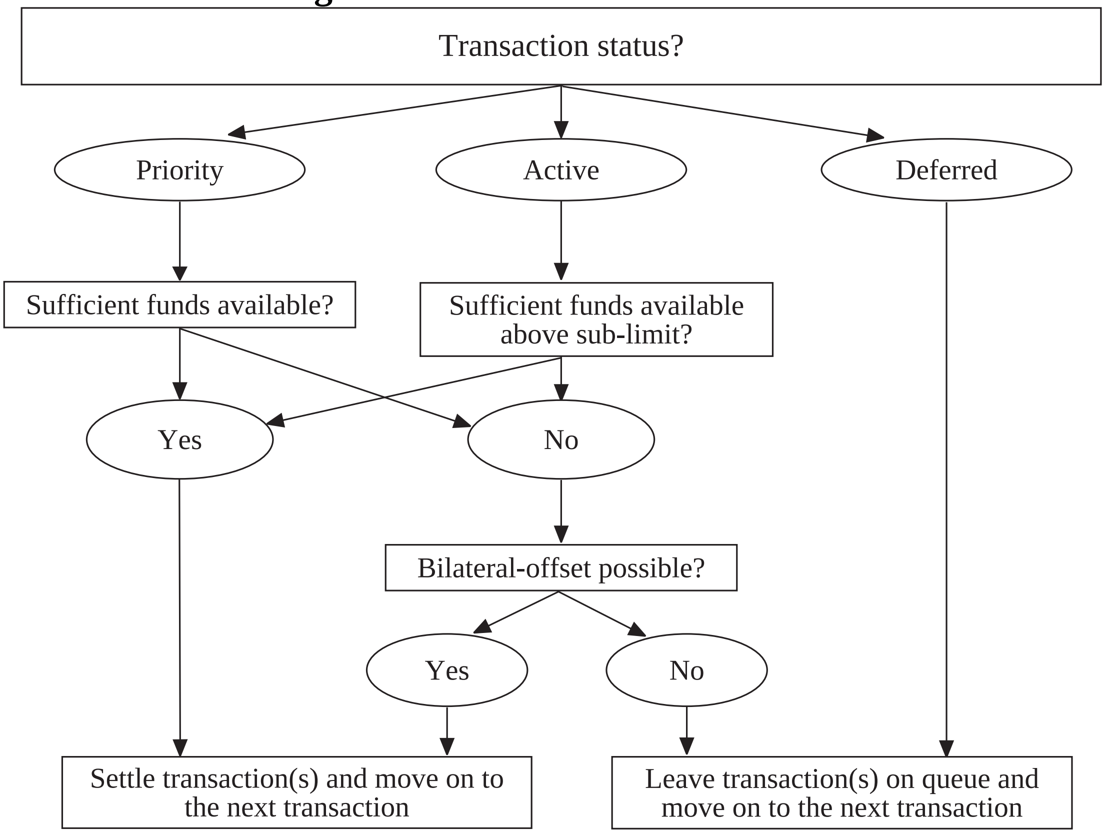


Table A1: Payment Status and Submission Times

Status when submitted to RITS	Status when settled in RITS	Status when submitted to the simulator	Time when submitted to the simulator
Deferred	Active	Active	Settlement time in RITS
	Priority	Priority	Settlement time in RITS
Active	Active	Active	Submission time to RITS
	Priority	Priority	Settlement time in RITS
Priority	Active	Priority	Submission time to RITS
	Priority	Priority	Submission time to RITS

Note: In the pure RTGS system, all payments are submitted to the simulator at the time they were settled in RITS and payment status is irrelevant.

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