Simulation Analysis: A Tool for Examining the Balance between Safety and Efficiency in Canada's Large Value Transfer System

Neville Arjani

A well-functioning large-value payment system (LVPS) is an integral component of any advanced financial system. In a market economy such as Canada's, virtually all economic transactions ultimately involve the transfer of funds between a buyer and a seller. An LVPS provides the electronic infrastructure necessary to facilitate exchanges of funds between participating financial institutions to discharge large-value payment obligations on behalf of their own business and that of their customers. The Bank of Canada maintains an active research program in this area, with specific emphasis on Canada's Large Value Transfer System (LVTS).[1] This research contributes to the Bank's broader objective of fostering a safe and efficient financial system in Canada.

Simulation analysis is a recent development in payment systems research. Simulation models are a useful tool since they can often be calibrated to replicate a specific LVPS environment. These models can then be used to assess the impact of changes in the structural arrangements and decision parameters of an LVPS without causing any costly disruption to the operation of the actual system. There is growing interest among central banks in using simulation analysis to conduct research on payment systems. As a contribution to this initiative, the Bank of Finland has developed a general simulation application, called BoF-PSS2, and is offering this software to other central banks free of charge.[2] The BoF-PSS2 is currently being used by over 30 central banks. The Bank of Canada has recently adopted the BoF-PSS2 and is calibrating this application to simulate the LVTS environment.

The Bank can use simulation analysis to understand the trade-off between safety and efficiency in the LVTS.[3] Improving safety and enhancing efficiency are the primary public policy objectives with respect to the design and implementation of an LVPS. A payment system should be safe in the sense that any disruptions within it do not spread to the broader financial system. At the same time, for its users, the payment system should provide a cost-effective means of sending payments. A system that is too safe (and therefore more costly) may discourage financial institutions from using it, and may instead lead them to resort to less-costly and more risky arrangements for sending payments.

There are different types of risks and costs inherent in an LVPS, and multiple trade-offs between safety and efficiency typically exist within each system.[4] This article focuses on a fundamental safety-efficiency trade-off—between settlement delay and intraday liquidity—with specific application to Canada's LVTS. Potential

1. The LVTS is owned and operated by the Canadian Payments Association (CPA). On average, approximately Can$140 billion is transferred through the LVTS each day. The Bank of Canada and 14 deposit-taking institutions participate in the system. The Bank of Canada also supplies the means of settlement and maintains oversight responsibility for the LVTS with a view to controlling systemic risk. For more information on the LVTS, see Dingle (1998) and visit the CPA website at www.cdnpay.ca.

2. The Bank of Canada is grateful to the Bank of Finland for developing the BoF-PSS2 and for allowing other central banks to use it.

3. Simulation techniques have been used by central banks for other types of payment systems research, such as stress-testing. Leinonen (2005) discusses simulation research conducted by central banks worldwide.

4. The risks most often cited in large-value payment systems include credit and liquidity risk, legal risk, operational risk, and systemic risk. See BIS (1997).

improvements to this trade-off will also be discussed. This article shows how simulation analysis can be used to evaluate such a trade-off using actual data on LVTS transactions and credit limits. It also shows how simulation analysis can be used to test hypotheses regarding improvements in the trade-off. In accomplishing this, the usefulness of the BoF-PSS2 as a research tool will be highlighted. The article concludes with some caveats related to the simulation analysis and suggestions for future research.

Settlement Delay and Intraday Liquidity in an LVPS: The Trade-Off

The nature of settlement delay in an LVPS

Participants in a large-value payment system typically maintain a daily schedule of payments that they must send through the system on their own behalf and on behalf of their clients. Payments must be completed by a certain time each day, where the time that a specific payment is due is determined as part of the underlying economic transaction. Most payments must simply be transferred by the end of the day. However, some payments sent through an LVPS are time sensitive. These may include payments related to the settlement of final funds positions in other important clearing and settlement systems, as well as payments associated with the daily implementation of monetary policy. Time-sensitive payments must be sent by a specific time each day.

Payment finality is achieved when an LVPS payment sent from one participant to another cannot be revoked or unwound under any circumstances, as in the case of participant insolvency. A key feature of a modern LVPS is that these systems offer immediate intraday finality—in other words, payments are considered final immediately upon being processed by the system.[5] As a result, recipients of payments can make prompt use of these funds without any chance of a payment being subsequently revoked or unwound.

This article defines settlement delay as a potential time lag occurring between a participant's intended submission of a payment to the LVPS (i.e., when the payment is due) and when the payment becomes final (i.e., when it is processed by the LVPS). Settlement delays in an LVPS are often related to the liquidity constraints faced by participants that are associated with the provision of intraday credit. This will be discussed in greater detail below.

The consequences of settlement delay in an LVPS

Given the high speed and high value of daily payments processed through an LVPS, coupled with the fact that many of these payments are time sensitive, the costs associated with settlement delay can be potentially significant.

A participant that is unable to meet its payment obligations when they are due may face certain costs because of the delay, such as reputation damage with its peers and, possibly, a loss of its clients' business. For the intended receiving bank awaiting payment, not obtaining incoming funds when they are expected will result in a shortfall in its intraday funds position. If this participant is planning on using these funds to send its own payments, then those payments may also be delayed. A comparable disruption to the funds position of the receiving bank's client is also likely, resulting in potentially broader consequences for economic activity.

The existence of settlement delay may also intensify the potential losses associated with other risks in the LVPS, such as operational risk. An operational event (such as a computer outage that prevents one or more participants from sending payments) will likely have a larger impact in a case where a number of payments remain unprocessed at the time the incident occurs (Bedford, Millard, and Yang 2005). Also, if faster, more efficient processing of payments helps to encourage greater use of an LVPS versus systems that are not as well risk proofed, it follows that reductions in settlement delay may translate to lower systemic risk in the broader financial system.

5. The discussion here focuses on the "modern LVPS," which refers to real-time gross settlement (RTGS) and RTGS-equivalent LVPS, such as Canada's LVTS. For a complete description of these systems, see BIS (1997, 2005).

Intraday liquidity in an LVPS

Intraday liquidity refers to a participant's ability to meet its outgoing payment obligations in a timely manner. In today's LVPS, participants require intraday funds in order to send payments through the system. Maintaining intraday liquidity, therefore, means having the funds available to complete payments as they become due. This is typically costly for participants. For example, an important source of intraday funding for participants is the provision of intraday credit. If intraday credit was free and unlimited, participants could borrow funds any time they needed to send a payment, and no settlement delay would occur. However, although settlement delay would cease to exist in this case, lenders of intraday credit (typically central banks) would face large risk exposures vis-à-vis borrowers, which is not desirable from a public policy perspective.

Consequently, intraday credit in an LVPS is not free and unlimited, but rather, is typically subject to eligible collateral requirements (which may entail an implicit opportunity cost), explicit interest charges, or caps on credit provision. These intraday credit constraints may limit participants' intraday liquidity in an LVPS, thus increasing the potential for settlement delay in the system.

The trade-off

Consider a hypothetical reduction in the amount of intraday funding maintained by participants in the LVPS. What would be the impact of this reduction? It is anticipated that such a reduction would entail both a "cost" and a "benefit" to system participants. The benefit to participants is clear: a reduction in available intraday funds will directly result in lower funding costs (e.g., reduced collateral requirements). However, participants rely on intraday funds to send payments to each other. Reducing the amount of funds available to a participant increases the likelihood that it may not have sufficient liquidity when its payments become due. Thus, the cost associated with this hypothetical reduction in intraday funding is a potential increase in the level of settlement delay in the system.

Payments that cannot be processed when due because of a participant's lack of intraday liquidity may be held in that participant's internal queue. Alternatively, these payments could be submitted to the LVPS and held in the system's central queue if one is available. Under standard queuing arrangements, internally and centrally queued payments are released and processed on an individual basis when the sending participant's intraday liquidity improves to the extent that these payments can be processed. This increase in intraday liquidity may be a result of the participant receiving a payment from another participant or acquiring more intraday credit.

It is also expected that the greater the amount of intraday funds removed from the system, the greater will be the magnitude of the accompanying settlement delay. The number of payments becoming queued when due, and also their duration in the queue, will increase as intraday liquidity is further reduced.

A graphical representation of the trade-off

Following a general analytical framework proposed by Berger, Hancock, and Marquardt (1996), the trade-off between settlement delay and intraday liquidity can be characterized as a decreasing convex curve in delay-liquidity space (Chart 1).

Each point in the space represents a possible delay-liquidity combination necessary to produce a given amount of payments. All points along, and above, or to the right of the curve represent feasible delay-liquidity combinations, given the current LVPS technology. Movements along the curve from right to left capture the idea that, as intraday funding is removed from the system, settlement delay is expected to rise at an increasing rate. Points below or to the left of the curve, although preferred, are currently unattainable and can be achieved only through some form of innovation in the LVPS technology.

Improving the trade-off between settlement delay and intraday liquidity

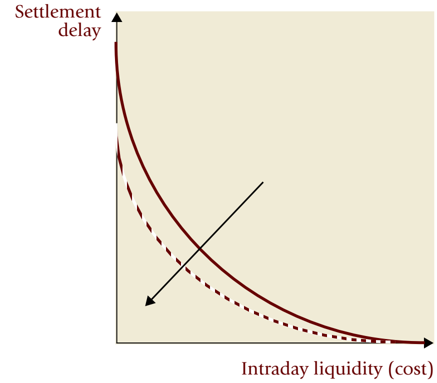
Given the potential consequences of settlement delay, an improvement in the trade-off is desirable. An improvement is characterized by a reduced level of settlement delay for each amount of intraday liquidity. This can be achieved either through quicker processing of queued payments or fewer payments having to be queued upon submission. Such an improvement is represented by a downward shift of the trade-off curve closer towards the origin (dotted line in Chart 1).

As mentioned above, an innovation in LVPS technology is needed to improve the trade-off. The addition of a complex queue-release algorithm to the central queue represents one such innovation.[6] These algorithms are designed to simultaneously search for and offset batches of centrally queued payments.

Under standard queuing arrangements, payments are released from the queue *individually* when a participant's intraday liquidity is sufficient for them to be processed. In contrast, under central queuing with a complex queue-release algorithm, the simultaneous processing and release of a batch of queued payments is attempted at regular intraday intervals. In this case, for the entire batch of payments to be released from the queue, participants need access only to sufficient intraday funds to cover any possible net debit (negative) position resulting from the payment offset.

With a complex queue-release algorithm, participants have lower funding requirements for the release of queued payments. Thus, even where intraday liquidity has been hypothetically reduced in the system, the processing time for queued payments can be faster, and average intraday queue length could decrease, compared with a standard queuing arrangement.

Chart 1 Trade-Off between Settlement Delay and Intraday Liquidity



Simulation Methodology

It could be interesting to apply this concept to the LVTS environment, and simulation analysis facilitates such an exercise. Specifically, the BoF-PSS2 can be used to assess whether there is a trade-off between settlement delay and intraday liquidity in the LVTS, and whether the introduction of a complex queue-release algorithm could improve this trade-off. This section outlines the simulation methodology involved in this analysis, including a description of the data used, details of the operation of the BoF-PSS2, and how the analysis can be specifically applied

6. For discussion related to the benefit of these algorithms, see for example BIS (2005) and Leinonen (2005).

in the LVTS environment. Box 1 provides some relevant background on the LVTS. Dingle (1998) contains a more thorough description of the system.

It should be noted that the current version of the BoF-PSS2 does not contain bilateral credit limit (BCL) functionality (Box 1), which is an important component of the LVTS.[7] The simulation model used in the analysis recognizes only multilateral credit limits, and this is considered further in the concluding section. In addition, the analysis focuses on Tranche 2 (T2), since it is the dominant payment stream in the LVTS.[8]

Description of the data

Three months of data on LVTS T2 transactions and credit limits were collected between July and September 2004. Transaction data include the date and time that each transaction was submitted to the LVTS, as well as the value of the payment and the counterparties involved in the transaction. It is assumed that the time stamp attached to each payment represents the intended submission time of the payment. Data on credit limits include the value of the Tranche 2 net debit cap (T2NDC) available to each participant, as well as the date and time that the value of the T2NDC is effective. The value of a T2NDC may change from day to day and also within each day.

Description of the BoF-PSS2

Although it does not have bilateral credit limit functionality, the BoF-PSS2 operates in a similar fashion to the LVTS. Payments are submitted for processing in order based on a time stamp. A submitted payment is processed by the simulator if the payment does not result in the sending participant incurring a net debit position that exceeds its T2NDC. Payments that cannot be processed upon submission because of a sender's lack of intraday liquidity are stored in the simulator's queue. The BoF-PSS2 offers various

7. A new version of the BoF-PSS2 containing BCL functionality is expected to be available in early 2006. Bank of Canada staff are participating in the development of this new version.
8. On an average day, approximately 86 per cent of daily LVTS payment value and 98 per cent of payment volume is sent through the T2 payment stream.

Box 1

Background on the LVTS

In the LVTS, final settlement is guaranteed under all circumstances, thus virtually eliminating systemic risk. This is facilitated by the system's real-time risk controls (net debit caps), collateral requirements, and a residual guarantee provided by the Bank of Canada.[1] Guaranteed settlement enables immediate intraday finality on all payments processed through the system.

The LVTS consists of two payment streams—Tranche 1 (T1) and Tranche 2 (T2). Each stream has its own risk controls and collateral requirements. Participants may use either stream to send payments. T1 is a defaulter-pays stream, since any T1 net debit position incurred by a participant must be fully secured with eligible collateral pledged by that participant. In T2, a survivors-pay collateral pool is used. At any time, there is sufficient T2 collateral pledged by participants to cover the largest possible T2 net debit position of any participant. The T2 payment stream greatly economizes on participants' collateral requirements relative to T1. As a result, the majority of daily payment activity in the LVTS is conducted in T2.

In T2, participants have the ability to draw on a T2 line of credit. Specifically, LVTS participants grant bilateral credit limits (BCLs) to each other. The value of a BCL represents the maximum bilateral T2 net debit position that the grantee may incur vis-à-vis the grantor at any time during the daily payment cycle. A participant's T2 multilateral intraday credit limit, known as its T2 net debit cap (T2NDC), is calculated as the sum of all BCLs granted to it multiplied by a system-wide parameter (SWP), which is equal to 0.24.[2] A participant's T2NDC represents the maximum multilateral T2 net debit position that it can incur during the daily payment cycle. A payment submitted to T2 is processed if it does not result in the sending participant incurring a net debit position exceeding either its BCL vis-à-vis the receiver or its T2NDC.[3] Participants are required to pledge eligible T2 collateral equal to the value of the largest BCL that they grant to any other participant, multiplied by the SWP.

1. In the unlikely event of multiple participant defaults in the LVTS, the Bank will exercise its residual guarantee to facilitate settlement by realizing on available collateral and absorbing any residual loss.
2. When the LVTS began operations in February 1999, the SWP was equal to 0.30. Since then, it has been gradually reduced and has been equal to 0.24 since March 2000. See LVTS Rule No. 2, available at www.cdnpay.ca.
3. For more on LVTS risk controls, see Engert (1993) and McVanel (2005).

queue-release algorithms for users to choose from, representing alternative queuing arrangements typically available in an LVPS.

The BoF-PSS2 generates a variety of time-series output reports when a simulation is completed. These reports include statistics on the number and value of processed and unprocessed payments. Data on the use of credit limits, as well as the number and value of queued transactions, can also be observed. BoF-PSS2 users can choose the frequency at which these output data are generated. For instance, output statistics can be reported daily, as well as on an intraday basis, in intervals ranging from one to sixty minutes. Moreover, these output data are available at the aggregate system level and also at the individual participant level.

Application to the LVTS

Imposing a hypothetical reduction in participants' intraday liquidity is a key aspect of the analysis. In applying the analysis to the LVTS, this reduction is generated by lowering the intraday credit available to participants. Holding BCL values constant, participants' T2NDC value can be reduced by lowering the value of the system-wide parameter (SWP). Similar to the earlier discussion, reducing the SWP is expected to entail both a cost and a benefit to participants. The former arises because participants will find it more difficult to meet their payment obligations when they are due, since they become constrained by their T2NDC more quickly and frequently during the day. Consequently, the level of settlement delay in the LVTS is expected to rise. However, a reduced SWP will also benefit participants since it lowers the value of T2 collateral required and the related costs.

The simulation analysis involves running two batches of eight simulations. Each of the simulations in a batch is characterized by a reduction of intraday credit available to each participant. To achieve this, additional datasets on credit limits are created over the sample period using lower hypothetical SWP values. Transactions data remain the same in each of the simulations, based on the assumption that participants' payment-sending behaviour remains unchanged during the analysis.

LVTS participants generally utilize internal queues to manage the release of their payments to the system. Internally queued payments are released whenever a participant's intraday liquidity is sufficient for them to be processed. The first batch of simulations is meant to replicate, as closely as is possible, this internal queuing arrangement. To accomplish this, a standard queue-release algorithm has been specified in the BoF-PSS2.

Three daily measures of settlement delay are calculated and averaged over the sample period for each of the simulations in the batch (i.e., for each level of intraday liquidity). These measures are as follows:

1. Daily Proportion of Unsettled Transactions Value: This ratio is found by dividing the total value of unprocessed payments remaining in the queue at the end of the day by the total value of payments submitted by participants over the entire day.

2. Daily System-Wide Delay Indicator: Adopted from Leinonen and Soramäki (1999), this indicator can take on any value between 0 and 1. A value of 0 is attained when all daily payments are immediately processed with finality upon intended submission. A value of 1 is calculated when all payments become queued upon intended submission and remain there until the end of the day.

3. Average Intraday Queue Value: This measure represents the average intraday value of queued T2 payments.

The objective in running the second batch of simulations is to assess whether the introduction of a complex queue-release algorithm can improve the trade-off; i.e., reduce settlement delay associated with each amount of intraday liquidity. The LVTS currently employs a central queue complete with a complex queue-release algorithm. With this algorithm, queued payments are offset at regular intervals (every 20 minutes) throughout the day. Under current LVTS rules, participants are not encouraged to use the central queue.[9]

The second batch of simulations is therefore an experiment to assess whether increased use of

9. LVTS Rule No. 7 states that participants can manage their T1 and T2 positions in real time, and should therefore attempt to submit only those payments that will pass the respective risk-control test. Visit www.cdnpay.ca for more information.

Chart 2 Average Daily Proportion of Unsettled Transactions Value

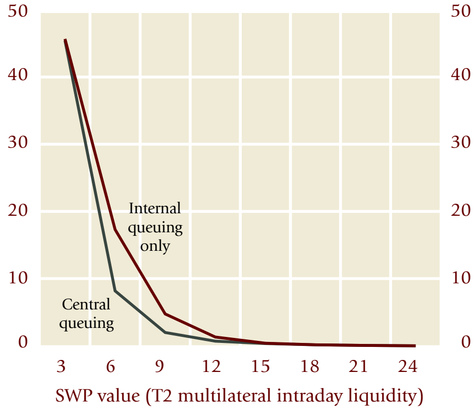


Chart 3 Average Daily System-Wide Payments Delay

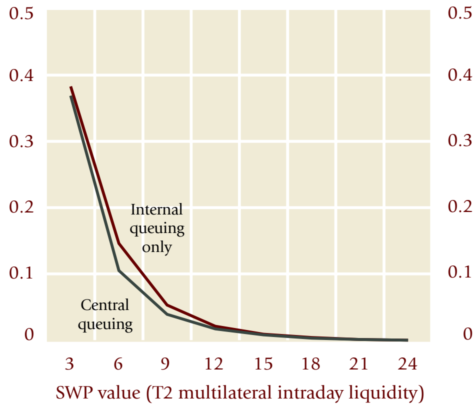
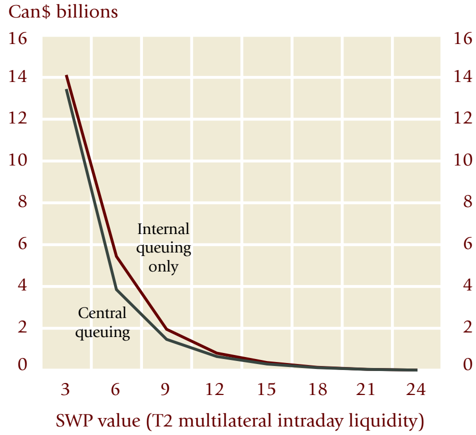


Chart 4 Average Intraday Queue Value



the LVTS central queue could potentially improve the trade-off. It is assumed that, under this alternative central queuing arrangement, participants no longer hold payments internally until they can be processed. Rather, all payments are submitted to the LVTS when they are due. Any payments not processed immediately enter the central queue.

For purposes of comparison, the same transaction and credit limits data are used in the second batch, and the same measures of settlement delay are calculated. The fundamental difference between the first and second batches is that a complex queue-release algorithm similar to that in the LVTS is specified to run in the latter batch every 20 minutes.

Simulation Results

Simulation results are provided in Charts 2 to 4. Each chart shows two curves corresponding to the two batches of simulations. The curve denoted "Internal queuing only" illustrates the results of the first batch of simulations. The curve denoted "Central queuing" depicts results estimated under the alternative central queuing environment.

The simulation findings confirm that a trade-off exists between settlement delay and intraday liquidity in the LVTS, and this relationship is consistent with the assumptions of the earlier graphical framework. Moreover, the introduction of a complex queue-release algorithm is shown to improve this trade-off. Settlement delay in the second batch of simulations is reduced for each amount of intraday liquidity according to all three measures.

The results indicate that the relative benefit of a complex queue-release algorithm (in terms of reduced settlement delay) increases as intraday credit availability is constrained further, reaching a peak when the SWP is equal to 0.06. In this case, the average proportion of unsettled T2 transactions value is reduced by 9 percentage points or about $10 billion (Chart 2), the average system-wide delay indicator is reduced by 28 per cent (Chart 3), and average intraday queue value is reduced by 29 per cent or about $1.6 billion (Chart 4) relative to the first batch of simulations.

The relative gains from the alternative central queuing arrangement begin to decline when the

SWP is reduced beyond 0.06. Close to half of the total value of daily submitted transactions remains unprocessed under both batches when the SWP is equal to 0.03 (Chart 2). At this SWP value, it is believed that participants' intraday liquidity is so constrained that only very small groups of queued payments can be processed each time the offsetting algorithm runs.

A further result of this analysis is that the level of settlement delay increases only marginally as the SWP is initially reduced from its current value of 0.24. This is an interesting finding, since maintaining participants' intraday liquidity (and the avoidance of settlement delay) is perhaps the primary objective in determining the value of the SWP. A reduction in the SWP from 0.24 to 0.18 is estimated to increase the average proportion of daily unsettled transactions value by only 0.15 percentage points under current internal queuing arrangements and 0.14 percentage points under the alternative central queuing arrangement (see Chart 2). Similar results are observed with the other two delay measures. As has been mentioned, reducing the SWP also produces a benefit for LVTS participants in the form of lower collateral requirements. Specifically, a reduction in the SWP to 0.18 reduces the total value of participants' T2 collateral required by about $750 million per day, on average, over the sample period, holding current BCL values constant.

Summary and Future Research

This research uses simulation analysis to examine the trade-off between safety and efficiency in an LVPS. This article describes a fundamental safety-efficiency trade-off—between settlement delay and intraday liquidity—and illustrates how simulation techniques can be used to evaluate this trade-off in Canada's LVTS. Simulation results indicate that a trade-off does exist between settlement delay and intraday liquidity in this system, and that this trade-off could be improved with greater use of the central queue and its complex queue-release algorithm. Moreover, the article shows that the SWP value could be reduced to as low as 0.18 at little cost in terms of delayed settlement, regardless of whether use of the central queue is increased.

It must be emphasized that these conclusions are preliminary, and the existence of certain caveats indicates that further work is necessary. Perhaps most importantly, the current analysis assumes that participants' payment-sending and bilateral credit-granting behaviour remains unchanged despite reductions in the SWP and changes in queuing arrangements. This assumption must be challenged. Further research on the factors underlying participants' behaviour, and anticipated developments in the BoF-PSS2, are necessary to conduct more robust simulation analyses in future.

Secondly, the article highlights the benefit of using a central queue equipped with a complex queue-release algorithm. However, it is also necessary to identify and assess the potential implications of such a development, which may not be captured by the current simulation results. For example, BIS (1997) argues that the availability of a central queue may motivate LVPS participants to take on increased credit risk. This could occur where participants have the ability to view information on expected incoming payments in the central queue. A participant, observing that incoming funds intended for one of its clients are waiting in the queue, may choose to credit the client's account with the value of these funds before they are received in the system. Thus, the participant would be exposing itself to credit risk until the payment is processed by the LVPS with finality.

Finally, further research is required to assess whether the benefit of a reduced SWP (in terms of lower collateral requirements) is greater than the associated cost in terms of a marginal increase in settlement delay. This entails attempting to quantify the (social) cost of settlement delay, and will likely depend on a number of factors including how time sensitive the delayed payments are.

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