JASPER PHASE III

SECURITIES SETTLEMENT USING DISTRIBUTED LEDGER TECHNOLOGY

OCTOBER 2018

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EXECUTIVE SUMMARY

The primary goal of Project Jasper is to evaluate the potential role for distributed ledger technology (DLT) in Canadian financial market infrastructures and any material benefits that could result from its adoption. Jasper Phase III expanded upon earlier phases to broaden the DLT ecosystem beyond wholesale payments to include securities settlement for TSX-listed equities. Jasper III was commissioned by Payments Canada, TMX Group, and the Bank of Canada in collaboration with delivery partners Accenture and R3.

The project involved a hands-on exploration of settlement and payment interactions in a private distributed ledger network by building and testing a proof-of-concept (POC) system that was connected to the existing market infrastructures. Securities and cash were brought on-ledger through the issuance of Digital Depository Receipts (DDRs) by CDS and the Bank of Canada, respectively, allowing POC participants to settle securities against central bank cash on the distributed ledger. Equity and cash DDR could be redeemed immediately after their transfer since settlements were final and irrevocable.

Several key features of the DLT platform showed promise during the POC experiment: financial market infrastructures were effectively integrated through a “loose coupling”; independent rules and conditions of token issuers were enforced on the ledger, allowing the DDR to be transferred “freely” in a shared ledger environment; participation restrictions were enforced through a private ledger and doorman service; and real-time ledger visibility was granted to market infrastructure and observer/regulatory nodes as required.

The POC introduced a credit extension process for broker participants that are not members of the payments system to access cash DDR on-ledger. This allowed these brokers to participate in the POC, and mirrors the need for brokers to receive credit from credit extenders in the current system. The introduction of credit extension in the POC, however, reintroduced credit risk in a DVP1 model that held promise for eliminating it.

DLT-based models that experiment with more fundamental departures from the current settlement process and market infrastructures ecosystem may be more likely to demonstrate operational cost savings and reduced back-office reconciliation efforts.

Our overall concluding hypothesis is that, while DLT still shows promise in terms of its ability to deliver efficiency improvements, a significant expansion of the scope of coverage of the ledger to include additional assets and the full trade and post-trade life cycle may be required to realize these benefits.

01. PROJECT OVERVIEW

Project Jasper's participants initiated the experiment more than two years ago to explore an integrated securities and payment settlement platform based on distributed ledger technology (DLT). Previous phases of the project focused on the clearing and settlement of high-value interbank cash payments using DLT. A key conclusion of Jasper Phase II was that material benefits of a DLT-based financial system might be realizable if the scope of the DLT system included the settlement of multiple assets.

Jasper Phase III investigated this hypothesis by exploring DLT-based interactions between the wholesale interbank payment infrastructure and the Canadian securities settlement infrastructure.

1.1 HYPOTHESES

Jasper III focused on a POC for a DLT-based integrated securities infrastructure providing delivery vs. payment (DVP) settlement to help re-imagine the payment exchange process of CDSX — Canada's clearing and settlement system for securities. The POC intended to bring together securities and cash ledgers for CDSX and participants in Payments Canada's Large Value Transfer System (LVTS) to facilitate daily consolidated cash reporting and Canadian-dollar settlement of CDSX obligations.

It was hypothesized that this implementation would enable the following benefits:

- **Technical efficiencies:** An integrated financial market infrastructure (FMI) solution may reduce technical frictions that exist in the current market infrastructure silos, resulting in better and more efficient securities and cash interactions among participants.
- **Operational efficiencies:** Common processing conditions, executed over a common computer network, may reduce participant costs to validate and reconcile delivery vs. payment transactions.
- **Cash and collateral efficiencies:** FMI integration may also bring opportunities to consolidate and optimize collateral requirements between large-value interbank payments and securities settlement systems.

1.2 KEY FEATURES

The POC focused on constructing a prototype that could provide insights against the stated hypotheses for all project participants. Fundamentally, the prototype was intended to substitute an integrated on-ledger DLT model for the current workflow that involves distinct settlement processes in CDSX and payment exchange on the LVTS.

The project translated this objective into the following key features:

- **Deployment of a private distributed ledger network:** A private network was required for settlement participants to simulate closed network interactions, as with the current model.
- **Tokenization of cash and equities positions:** Pledging, issuance, and redemption of cash owned by the LVTS participant and exchange-traded equities owned by the Canadian Depository for Securities (CDS) participants onto the shared ledger network, authorized by the Bank of Canada and CDS, respectively.
- **Implementation of select settlement conditions:** Transfer restrictions and credit extension processes were introduced to demonstrate asset interactions and oversight under different scenarios.
- **Execution of DVP1 equities settlement:** Involving the instantaneous settlement of netted and novated equities positions against cash, based on a central counterparty clearing (CCP) settlement model.

1.3 SCOPE

The POC adopted R3's open source Corda platform and was executed over an eight-week timeframe, based on a reduced but representative scope for demonstrating a happy-path settlement scenario. The project made the following scoping decisions:

- **Sample set of settlement participants:** A minimal set of participants was defined to represent the required roles in the equities settlement process, which consisted of one LVTS member, 14 CDS (non-LVTS) members, CDS, Bank of Canada, and Payments Canada.
- **As-is central counterparty settlement:** To explore the impact of DLT on the current centralized settlement model for exchange-traded equities, the CCP role was retained and trades were netted and novated, with the CDS acting as the CCP.
- **DVP settlement focus:** To enable exploration of cash and equities interactions during settlement, the POC emphasized the DVP portion of the settlement flow initiated by netted and novated settlement positions for each participant. This approach also de-scoped the complexities associated with current settlement algorithms.
- **Minimum viable asset interactions:** Basic permissions and restrictions in creation, pledging, transfer, and redemption on both cash and equities were defined dependent on the role of the participant, along with a basic credit extension concept to showcase the LVTS vs. non-LVTS member scenario.

1.4 KEY OBSERVATIONS

The POC demonstrated that a DLT-based system can functionally address the steps required to execute an irrevocable settlement of equities against central bank cash. This included the successful implementation of a DVP1 settlement flow of cash and equities between counterparties on a shared ledger.

Tokenization of both cash and equities on a shared ledger resulted in better asset interactions during DVP settlement relative to the currently siloed CDS and LVTS systems, whereby any participant or function can directly interact with the assets on-ledger. This technical efficiency gain may offer opportunities to streamline the implementation of various DVP models beyond traditional technologies and merits further exploration.

Enabling immediate finality of settlement resulted in the ability to instantly reuse cash and equity tokens. This concept of reuse in theory supports liquidity efficiency, in that the system only requires the minimum amount of liquidity necessary to settle each net position with true finality. In practice, participants pledge collateral and are issued credit to reduce or eliminate cash requirements intraday, and net settlement positions take into account existing equities positions. A closer examination of cash utilization in the settlement process would need to be conducted that accounts for the efficiencies of immediate token reuse.

Operational value for market participants remains to be validated, as most of the operational challenges for equities settlement occur between the point-of-trade execution through to DVP. A deeper consultation with participants would be required to determine the true extent of the benefits of process improvements.

Overall, a more ambitious re-imagining of clearing and settlement in a decentralized form, guided by market pain points in the settlement life cycle, would also create a more informed premise for benefits assessment.

1.5 RELATED WORK

Phase III of Jasper builds on the work of the first two phases, as well as experiments being performed by other central banks, such as the Monetary Authority of Singapore, the European Central Bank and the Bank of Japan, and the South African Reserve Bank.

Jasper I and II (2017a and b) constructed interbank payment systems using Ethereum (Phase I) and Corda (Phase II). The key lesson from this work was that there was still significant uncertainty as to whether DLT could deliver efficiency benefits for interbank payments compared with the efficient LVTS system that already exists. Phase II also showed that it was possible to have a liquidity savings mechanism for netting transactions. The conclusion was that significant efficiency gains were likely to be realized only if multiple assets were settled on the same distributed ledger system. It is primarily this last conclusion that set the stage for Jasper Phase III.

Project Ubin by the Monetary Authority of Singapore (2017a and b) concluded after two phases of work that DLT (in particular, Corda, Hyperledger Fabric, and Quorum) is able to satisfy the key functions of a real-time gross settlement (RTGS) interbank system in terms of volume, liquidity savings mechanisms, gridlock resolution, security, immutability, and resilience.

Project Stella by the European Central Bank and the Bank of Japan has also completed two phases (2017a and b). The first phase concluded that DLT systems would be capable of processing the typical volumes experienced by modern interbank RTGS systems. The experiment also confirmed that there was a trade-off between network size and performance.

Finally, improved resilience was a major potential benefit of DLT systems. The second phase of the project also examined DVP solutions for securities settlement, as did Jasper Phase III. The main goal of Project Stella was to examine the ability to do cross-chain atomic swaps with DLT. While showing this was possible, the experiment also demonstrated that it could yield a complicated solution that generated new challenges or risks that would need to be managed or solved.

Project Khokha of the South African Reserve Bank provided an examination of a quorum-based interbank payment system. The project demonstrated an ability to process transactions within two seconds across a geographically distributed network of nodes using a range of cloud and internal implementations of the technology.

The Australian Securities Exchange has outlined plans to replace its Clearing House Electronic Subregister System (CHESS) with a DLT-based model as part of its strategic initiative for replacing its core clearing and settlement system, in partnership with Digital Asset. Extensive testing was conducted around the clearing and settlement of cash equity transactions at near-production volumes, managing corporate actions, and maintaining security and participant records as part of the overall suitability evaluation.

02. DESIGN AND IMPLEMENTATION

The Jasper Phase III POC solution was built on a corda peer-to-peer DLT network using open source Corda V2.0 (The current version at the time of POC implementation). Refer to Appendix B (Corda concepts) for a detailed technical description of the Corda platform. This section of the white paper provides and overview of the solution implemented.

2.1 SUMMARY

To perform equity settlement on the POC platform, three ingredients are required on-ledger: the equity, the cash, and the position being settled. Once these are on-ledger, it is possible to perform an atomic and final DVP1 settlement transaction for each position. Finally, LVTS members were given the capability to extend credit on-ledger to CDS members, who then can use this for settlement.

2.2 ARCHITECTURE OVERVIEW

For the POC, each Corda node (brokers, bank, Bank of Canada, CDS, notary, etc.) is hosted in individual Azure virtual machine. Key components in the network are:

- **CDS node:** Tokenizes equities and acts as a central counterparty in settlement transactions.
- **Bank of Canada node:** Tokenizes cash.
- **Payments Canada node:** Observes cash transactions.
- **Broker nodes:** Participate in settlement transactions.
- **LVTS member:** Extends credit to non-LVTS members.
- **Notary:** Provides uniqueness consensus on the transactions.

2.3 TOKENIZING CASH AND EQUITIES

The tokenization of cash and equity both follow a digital depository receipt (DDR) model: they are secure digital claims for the underlying asset on deposit at the token issuer. Cash tokens are a claim issued by the Bank of Canada on Canadian-dollar deposits held in accounts at the Bank, and equity tokens are a claim issued by CDS for the underlying equity held at CDS.

An LVTS member can obtain cash tokens from the Bank of Canada by pledging cash from its existing account at the Bank. The Bank then issues a cash token for the given amount and transfers the same amount from the requestor's account to a "pool" account. In case of insufficient balance, the pledge will be rejected. Similarly, an LVTS member can redeem cash tokens it owns at the Bank of Canada in exchange for receiving the underlying cash in its account, transferred from the pool account.

In a similar manner, CDS members can obtain equity tokens from CDS by pledging the given equity in their CDS account and redeeming these tokens at CDS in exchange for receiving the underlying equity in their account.

This approach ensures that at any time, the amount of cash and equity on-ledger equals, and is backed by, the same amount in the corresponding pool.

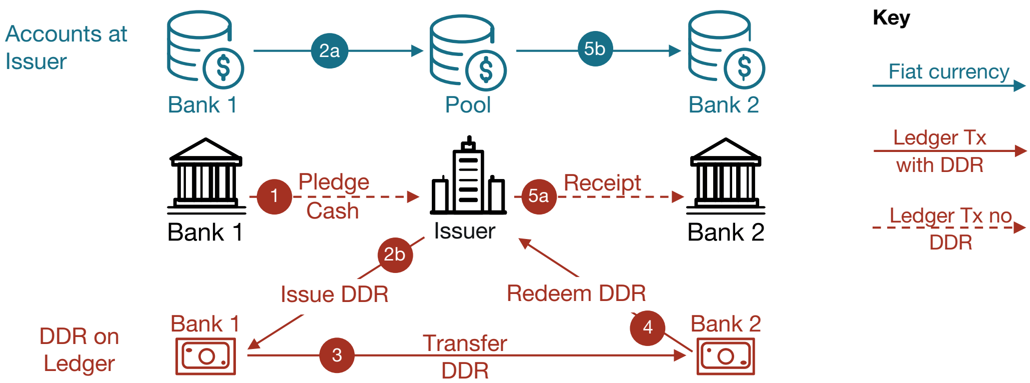

Figure 1: Tokenization

2.4 ONBOARDING POSITIONS

In the existing process, the exchange sends a file containing all trades for the day to CDS, which CDS then novates and nets, producing a file with the net settlement positions for each participant against the central counterparty, mirroring the existing process. The POC process starts by onboarding the positions in this file onto the ledger. Once onboarded, trade positions for each participant are in a pending state.

2.5 SETTLEMENT TRANSACTIONS

The settlement of an individual netted position is implemented as a single atomic Corda transaction, meaning it either succeeds fully or fails fully. This transaction takes as input the position to be settled as well as the cash and equity tokens required to settle it. If successful, it consumes the inputs, marking them as no longer valid. It also produces new cash and equity tokens as defined by the position. If it fails, all inputs remain valid, and no outputs are produced.

Consequently, the transaction achieves DVP: immediate and final exchange of equity and cash for the given position. The cash asset being settled for the payment side of the transaction is cash DDR. Because the central bank will exchange cash DDR for balances held at the central bank, the settlement achieves DVP1 in central bank cash.

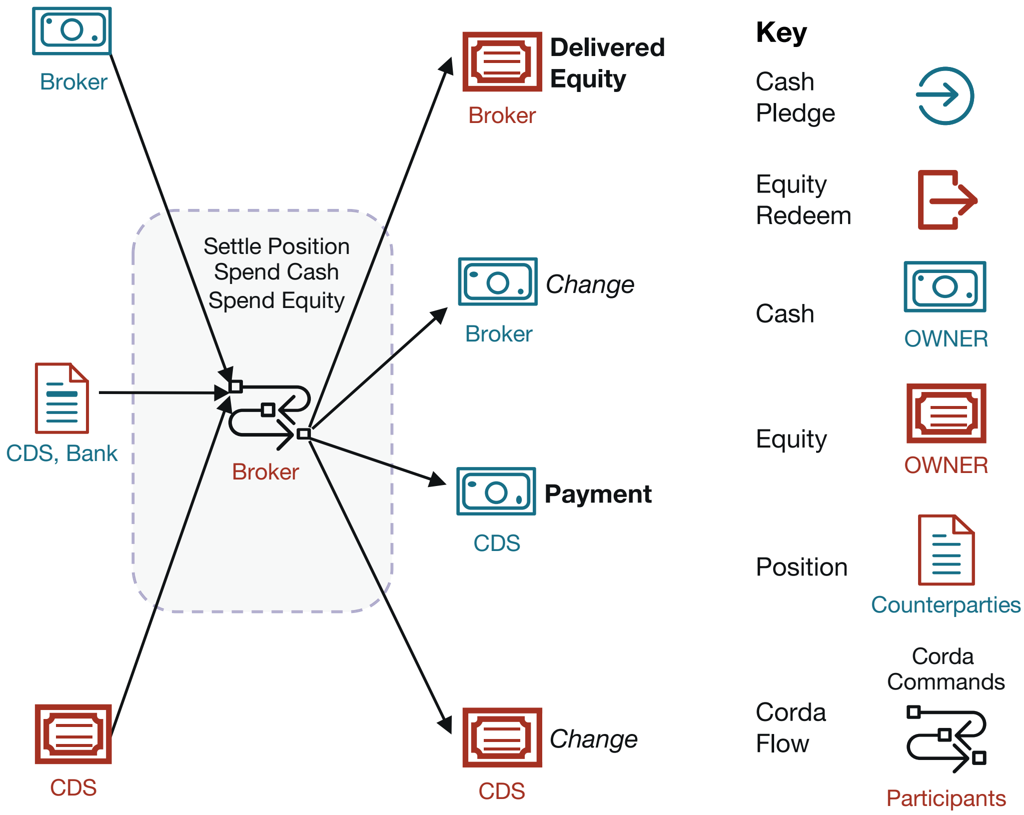

Figure 2: Settlement

2.6 SETTLEMENT PROCESS

The settlement process attempts to settle all open positions. The positions are ordered by the International Securities Identification Number (ISIN) and then by decreasing value. The process tries to settle each of these positions in order, skipping any position where a counterparty has insufficient cash or equity DDR for that ISIN on-ledger. The entire process is repeated until no further positions are settled. Appendix C (Example of the Settlement Process) demonstrates how this works.

2.7 CREDIT EXTENSION

Currently, most CDS participants, as broker-dealers, are not direct participants in the LVTS. To obtain intraday funds within CDSX and settle their purchase obligations, these participants rely on a credit extension by an extender of credit in CDSX. To settle their end-of-day payment obligation during CDSX payment exchange, they rely on a designated banker who is an LVTS member to make and receive their end-of-day payments in the LVTS on their behalf.

To reflect these real-world conditions, the POC assumes that the CDS broker-dealer participants do not have accounts at the Bank of Canada. As with the current situation, they rely on a designated banker — the LVTS member — to meet their net payment obligation in CDSX. Two differences are apparent. First, the net payment obligation is required at the beginning of the settlement cycle in the POC, as opposed to at the end of the settlement cycle in the current state. Second, since the pay-in established in the POC produces the funds that are used to settle purchases in the settlement system, the broker-dealer's banker also necessarily acts as the credit extender for that participant. In the current system, credit is created in the settlement system intraday, whereas in the POC a central bank-backed settlement asset (the cash DDR) is transferred ("on credit" from the LVTS member) to broker-dealers to be used as funds intraday.

The LVTS member node is given the ability to lend cash DDR to all CDS members (non-LVTS members) on-ledger in a three-step process. First, one or more CDS members requests credit extension from the LVTS member. Next, the LVTS member performs a pledge at the Bank of Canada, as described above, to obtain the required cash on-ledger. (This step is not required if the member already has the required cash on-ledger.) Finally, the LVTS member transfers the requested cash to the CDS members.

As mentioned in the scope in Section 4, the Project Overview of this white paper, credit risk controls associated with this on-ledger credit extension were not included in the POC, as the credit extension functionality was added to facilitate access to cash DDR for broker-dealers while maintaining the assumption that the current sets of participants across the LVTS and CDS are maintained for the POC.

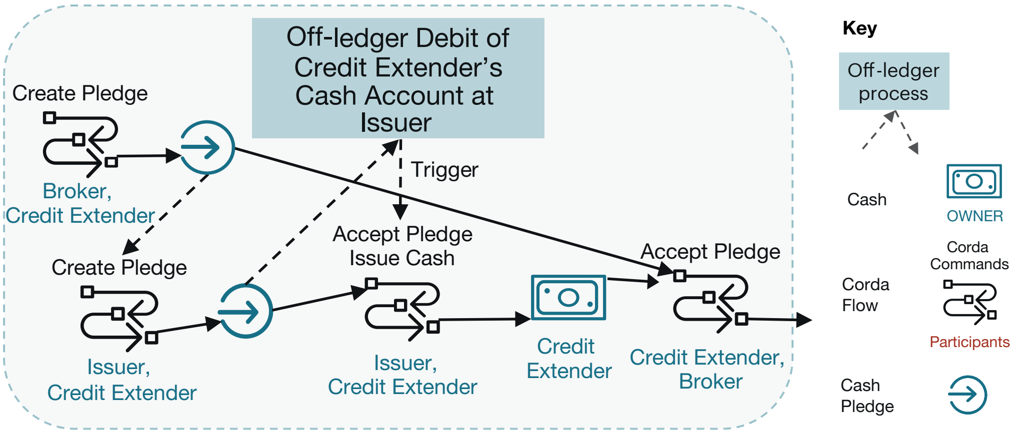

Figure 3: Credit Extension

2.8 END-TO-END PROCESS

Combining the features discussed above, the life cycle for the end-to-end process is as follows. First, outside of the POC scope, CDS receives the trades for the day from the exchange. For each broker-dealer and equity traded by that broker-dealer, CDS then computes a net position against itself as the central counterparty and sends a batch file with the resulting positions to the POC for settlement. At this point, the POC settlement process begins by taking the batch file of netted positions as the input.

- **Onboarding positions:** CDS receives the batch file and issues a state on-ledger for each position.
- **Pledges:** Each broker-dealer determines its net obligation in cash and for each equity, and then requests cash from the LVTS member and pledges equities, as required[1]:
    - **Cash:** Each broker-dealer with a net pay-in requirement requests a credit extension from the LVTS participant for the net amount due in the settlement process across all equities. The LVTS participant in turn pledges the total amount across all these requests and transfers the requested amounts of cash on-ledger to the brokers.
    - **Equity:** For each equity position with a net sell to CDS, each broker makes a pledge request to CDS for equity DDR in the amount of that position.
- **Settlement process:** This is a batch process, iterating over all open positions. CDS and the broker-dealer execute an atomic settlement transaction, exchanging the amount of cash and equity DDR specified by a given position state, thus settling that position.

  The cash and equity DDR produced as the output of one position settlement are used in subsequent position settlement transactions as required.

1.To execute the first settlement transaction, CDS requires either cash or equities on-ledger. To this end, the POC chose to make CDS also pledge cash to the Bank of Canada. Because CDS has a net-zero position, this same amount is owned by CDS at the end of the settlement process.

- **Redemption:** After completion of the settlement process, broker-dealers can create a redeem request to obtain equities in their CDS account or request that the LVTS member make a redeem request for cash at the Bank of Canada on their behalf.

The diagram below depicts a sample life cycle from the perspective of a “buy” position, including credit extension and cash redemption.

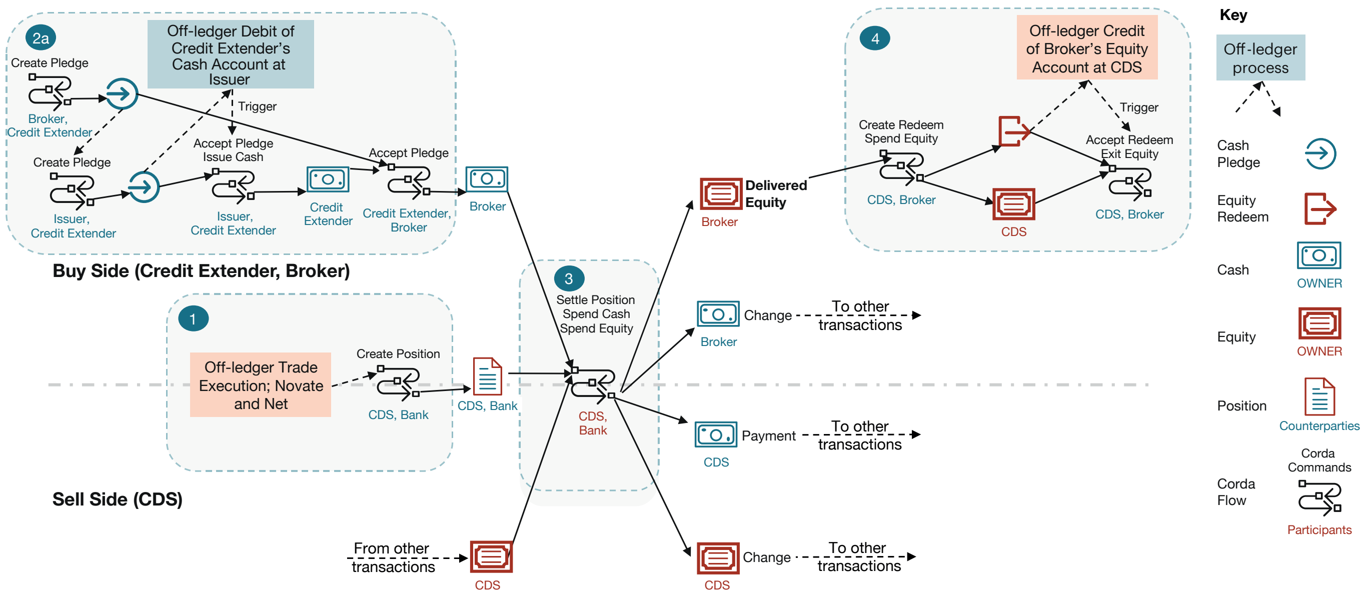

Figure 4: End-To-End Flow Overview

2.9 TEST SCENARIOS

As part of the POC, limited functional testing was conducted to ensure the proper working of the end-to-end settlement described above. The POC successfully settled 35,000 trade positions, with CDS members pledging to CDS the exact quantity of equities they were selling and obtaining the net cash amount required for the overall settlement from the LVTS member.

Due to limited time, computing resources, the deployment model (same subnetwork in the cloud), and the use of a non-enterprise version of Corda, the non-functional characteristics such as performance, availability, resilience, and security were not considered.

Some of these non-functional characteristics have been tested in other DLT-based POCs. Notable examples are Project Stella by the European Central Bank and the Bank of Japan and Project Khokha by the South African Reserve Bank. Project Stella tested whether a DLT-based payment solution can meet the performance of a real-time gross settlement system, and Project Khokha tested the operation of nodes under a variety of deployment models (on-premise, on-premise virtual machine, and cloud) and across distributed sites to process high-value payment transactions.

03. LESSONS LEARNED

Jasper Phase III enabled the three parties to explore and correlate some of the specific opportunities and challenges in building out a DLT-based FMI platform. This section outlines the respective key observations in detail.

3.1 TECHNICAL EFFICIENCIES

- The main output of the POC was the creation of a shared ledger for token interactions with cash and equities over a single distributed network.
- Tokenization of both cash and equities into a shared ledger enables direct access to assets by any participant or function, resulting in direct asset interactions during DVP.
- The Corda DLT platform enables loose coupling of the components controlling cash, equities, and positions in the ecosystem. This simplifies integration with the different participants' existing systems and is expected to ease extension to additional asset and transaction types.

3.1.1 Improved direct asset interactions

Under the current DVP1 settlement models, the infrastructure rails for securities and payments often operate in isolation and interact through a series of messaging steps to facilitate the finality of the transfer of securities ownership against the transfer of funds. This is referred to as an "interfaced model," although alternatives exist, such as an "integrated model," where the settlement accounts of participants are held at the securities settlement system (SSS), or a "prefunded account" model such as envisioned in the Jasper III POC, where cash accounts at the SSS are prefunded with central bank money (see European Central Bank, 2004).

Relative to the current DVP2 setup at CDS, where credit is used intraday and only one net payment is required at end of day for each participant, implementation of a DVP1 model using the LVTS to settle the payment for each equities settlement according to an "interfaced model" would require, on average, an extra 35,000 LVTS transactions per day, many of which would be for small amounts. While this increase would more than double the average of 32,000 transactions handled per day by the LVTS, its processing capacity far exceeds these amounts. These transactions would be linked, however, to DVP settlements that would require a tighter integration between systems to ensure appropriate DVP conditionality and for adequate operational risk controls to exist as the settlement flow traverses the independent FMI systems.[2] Using DLT enabled the integration of the CDS equity settlement system with the Payments Canada interbank cash payment settlement system (the LVTS) to generate DVP1 settlement without the large increase in LVTS transactions mentioned above. This was achieved without a rebuild or tight integration of the current systems to generate DVP1 using traditional technology. Future work should assess the cost of creating an integrated as opposed to an interfaced settlement vs. payment infrastructure, particularly if market demand for DVP1 becomes more prominent over time.

2. The current POC design would also require a similar number of net new "transactions" between the POC and the issuers of DDR due to the requirement for equities and cash to be pledged/redeemed at the issuing authority and populated on-ledger.


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3.1.2 Loose coupling and ease of change

Another challenge that would result from closer coupling of CDS and the LVTS to achieve DVP1 would be the complicated governance of the separate assets by the two FMIs involved. Upgrades or changes to the conditions of one asset may affect the other, with no obvious benefits to outweigh the risks. This could be solved in theory by combining the equity and cash settlement systems into one platform governed by a single central authority.

However, DLT enables an easier step forward by permitting a loose coupling of two separately governed systems without compromising the control of either authority over its system or assets. By issuing tokens using a DLT system, central bank-backed cash digital depository receipts can be used for settling securities transactions in the POC environment without the further involvement of the central bank in verifying each transaction.

By providing the appropriate assurance to the issuer that contracts on the DLT platform are well defined, the central bank can feel more comfortable that this “token in the wild” can be used safely in a decentralized environment outside the boundaries of the RTGS to settle multiple asset types, make payments, etc.

By design, the Corda platform allows for loose coupling of the processing conditions and validations over the different asset types. Specifically, there is no dependence on the equity DDR and its contract, transactions, and flows by the cash DDR issuer, the Bank of Canada. Changes in equity contracts, transactions, or flows, or a change of equity notary do not affect the cash life cycle in any way. In other words, each authority has full control over the nature of the assets it issues onto the ledger.

As a result, on-ledger DVP1 settlement could be implemented using DLT without some of the challenges of integrating multiple FMIs, even though it still involves two asset types—cash and equities—in one transaction. The use of DLT avoids the challenges of implementing tight integration between the two issuers or between the securities settlement system and the payments system.

There are established means of coupling, or integrating, systems such as message queues, object request brokers, APIs, and so on. These ultimately result in an interaction, specifically, a remote procedure call, between two systems, where the result of the interaction is stored within the two systems (it is possible for message systems to store messages).

In the case of a DLT, however, the result of the interaction is on the ledger, and is essentially a third system, and the representations of the financial instruments (the tokens) issued exist on the ledger itself. Hence, the ledger represents a common space among participants where tokens can exist and interact, uncoupled from in-house systems, resulting in loose coupling.

3.2 OPERATIONAL EFFICIENCIES

3.2.1 Operational cost savings for market participants remain to be assessed

One of the project's hypotheses stipulated the potential for reconciliation benefits for settlement participants, which was deduced from the inherent characteristic of a shared ledger in providing transactional transparency and trusted records to participating entities.

In the current system, participants are engaged in several activities that determine their securities positions and liquidity requirements within the securities settlement system. Examples of this include securities lending activities and the settlement of physically settled derivatives products upon close-out, exercise, or expiry. Additionally, participants must reconcile the positions of their clients against their own books and obligations in CDSX.

The POC was limited only to the settlement of exchange-traded equities after novation and netting by CDS. As a result, participants would likely not be able to reduce back-office reconciliation efforts. To realize more of the potential reconciliation gains across participants, it would be necessary to expand the scope of research to include (i) the entire, or substantial, aspects of the full post-trade clearing and settlement process and (ii) additional activities that affect securities positions and delivery obligations, such as securities lending and derivatives.

3.3 CASH EFFICIENCIES

3.3.1 Immediate reuse and redemption of cash and equity DDRs

The atomic settlement transaction achieves finality once all participants in the transaction and the notary agree and have signed the transaction, thereby achieving consensus. Proceeds of the settled cash and equity tokens can be reused immediately upon completion of the settlement transaction, either in subsequent settlements on-ledger or by redemption at CDS or the Bank of Canada for use off-ledger.

For equities, the result is not materially different from the current state. The DVP2 settlement model within CDSX delivers equities to the buyer in gross intraday, and these equities are immediately available in the buyer's account to be used for other purposes, including delivery in subsequent transactions.

For cash, the current process allows for immediate reuse of funds within CDSX intraday, but final cash settlement occurs via LVTS at end of day. Participants in CDSX are unable to withdraw a positive funds balance from equities sales intraday and must generally wait until end of day to receive the final payment for their equities transactions.

The DVP1 settlement model employed in the POC allowed for the immediate reuse of cash and equities DDR for subsequent settlements or for redemption at the issuing authority. Participants were required to pay in their net cash requirement at the beginning of the day. This requirement diverges from the current model at CDS, where participants make collateral-backed payments intraday within CDSX and settle their net payment obligation at the end of the day during CDSX payment exchange.

This change in payment timing for equities settlement would have an impact on participant cash managers and back- offices. The pay-in requirement in the POC allowed participants to redeem funds received intraday from equities settlements for use outside the settlement system. The trade-off is that participants would not benefit from the liquidity and collateral optimization functionality offered by CDS today and assured by the settlement system risk model. The extent of operational impacts on participants was not investigated in the POC, but should be considered further.

3.3.2 Cash optimization for broker-dealers

For any settlement process that provides finality on the cash leg, all participants must contribute at least the net cash amount due to pay aggregated overall positions. The algorithm implemented in the POC enforces the requirement that CDS broker-dealer participants provide exactly this amount, or the minimum cash amount, which achieves optimal cash efficiency.

This means that about half the participants will provide a positive amount of cash, plus whatever equities they are due to deliver, and the remaining participants need only provide the equities they are due to deliver, and no cash whatsoever. However, CDS, is required to hold an amount of cash to start the settlement process that is equal to the cash required for the single largest equity purchase based on the net positions of participants. This is an outcome of the CCP model: in every position settlement, CDS is one of the counterparties, so for the first transaction, CDS will need cash DDR on-ledger.

More advanced settlement algorithms can reduce or eliminate this requirement. This is an area for further study.

3.3.3 Liquidity vs. settlement efficiency

The test case conducted for the POC assumed that all participants had exactly the net amount of equity DDR and cash DDR required to settle all their net positions for the day from the input batch file. In practice, participants do not necessarily have all equities available to deliver for the morning batch settlement process, as they may receive or source equities for same-day delivery from other activities, such as securities lending later in the day.

This affects the resulting settlement order, as some transactions are queued due to insufficient funds or equities. The amount of liquidity required intraday to facilitate timely settlement of positions can be materially greater than the net amount due at end of day, especially where the avoidance of longer queue times is a priority.

Further analysis of the effects of cash- and equity-restricted accounts could be explored to learn more about how the effectiveness of the POC settlement algorithm would be affected by these restrictions, and whether larger amounts of prefunded liquidity may be desirable to improve the efficiency of batch settlements in these cases.

3.3.4 Liquidity impact requires scope extension

The POC approach collapses the current liquidity requirements for equities settlement and the cash requirement for end-of-day cash settlement in the LVTS into one requirement, which will have an impact on participant liquidity accounts. Because the CDS liquidity accounts do not play a role in the POC settlement process, the POC approach removes the liquidity requirements for equity settlement from those accounts.

However, the same liquidity accounts are also used to settle obligations in CDSX that result from other activities, including some with complex interdependent relationships, as depicted below. For example, this liquidity in CDSX is also used for fixed-income settlements and purchases of the underlying asset from derivatives transactions, and securities lending may make securities available for settlement (with an impact on liquidity for those buying these now-available securities). Liquidity that becomes available in one process, whether from an equity or fixed-income sale, or the delivery of equities under a derivative contract, may be reused in another.

The net impact of the alternate cash-settlement model employed in the POC for exchange-traded equities settlement on the total liquidity needs of participants within CDSX owing to their combined settlement activity was beyond the scope of the POC. Therefore, it is not yet possible to draw clear conclusions about the impact on the liquidity requirements of the overall system.

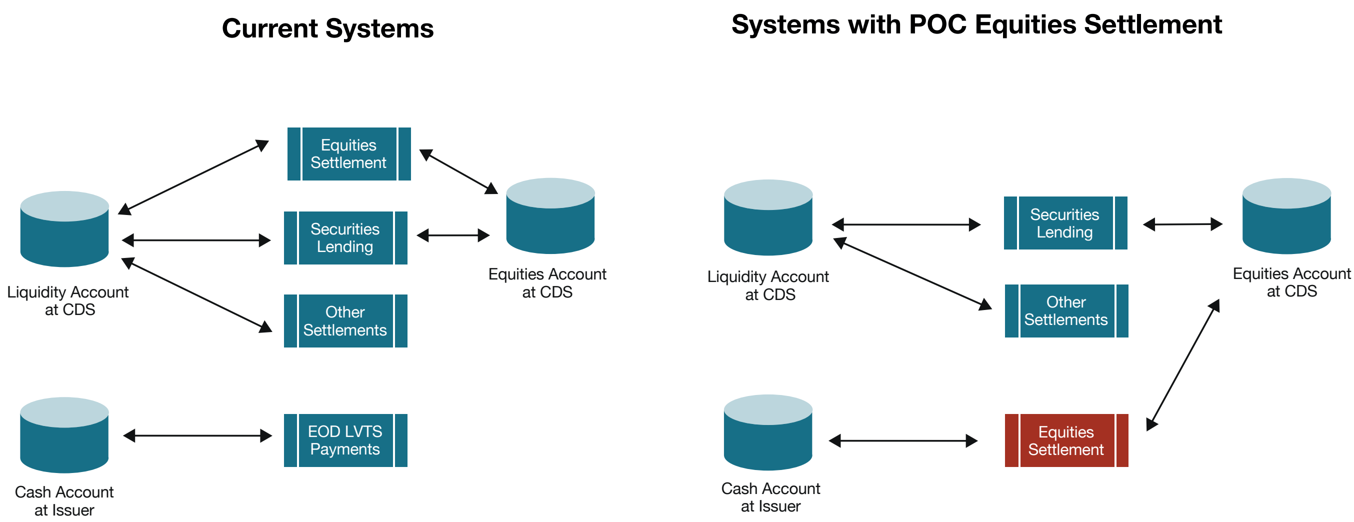

Figure 5: Settlement Infrastructure—Systems Interaction

3.4 OBSERVATIONS BEYOND OUR HYPOTHESES

3.4.1 Credit extension concept showcased intricacies of implementing participation rules

A complicating factor in Phase III and the Canadian securities settlement system is that the list of participants in the LVTS is different from those in CDS. This is due to differing business needs and the participation requirements of these systems. The POC took the current state of participation in the securities settlement system and the LVTS as a given and maintained separate participant pools between CDS and the LVTS to test the feasibility of maintaining this partitioning.

The CDS members in the POC did not have direct access to Bank of Canada cash, reflecting their participation in CDS today. To allow CDS members access to the cash required for settlement, the POC implemented a simplified credit extension model, where the LVTS member can access cash DDR from the Bank and subsequently extend credit to CDS members.

Credit extension was initiated by a request from CDS members for cash DDR from the LVTS member. The LVTS member obtained cash DDR through a pledging transaction at the Bank of Canada before transferring it to the CDS members. This separation was ensured by designing the system such that each participant could perform only those transactions or functions they were authorized to complete. This was enforced through a doorman service, a notary, and smart contracts provided by the Corda platform. Each component was required to ensure that a participant was able to perform only the task for which they had authorization.

This concept raised three points:

- The credit extension mechanism by way of cash DDR token transfer would require collateralization and a credit risk model to manage the risks to the LVTS member that extended the credit. These are beyond the scope of the POC to consider.

- The DVP1 settlement model was expected to reduce risks on the funds side of the securities settlement; however, the introduction of credit undermines this potential benefit. Alternative models that retain more of the risk-reduction benefits of the DVP1 feature are a subject for further study.

- Instead of a credit-extension mechanism, the challenge could have been addressed simply by allowing all participants to be members of both the LVTS and CDS — a first step in combining the systems into one. Such a change would require extensive policy discussion.

3.4.2 Retaining transaction confidentiality for participants

Corda provides a basic level of inherent transaction confidentiality due to the peer-to-peer nature of transactions. Only participants involved in a transaction — the counterparties and the notary — and any regulatory observers will see that transaction. This contrasts with most DLT platforms, which instead broadcast all transactions to all participants. Corda thus has an inherently better starting position preserving transaction confidentiality than global-broadcast DLT platforms.

However, if outputs of a transaction — cash or equity tokens — are reused in subsequent transactions, the recipient will need to verify that the tokens were originally issued by the authorized issuer (Bank of Canada for cash, and CDS for equities), and are a valid "descendant" of that original token. The approach built into Corda to achieve that is to provide the full "transaction lineage" to the recipient. This lineage consists of the transaction that transfers an asset to a recipient plus any previous transactions that are needed to provide a chain of provenance back to the original issuance of that asset. Without further countermeasures, information contained in the transaction lineage will be visible to the recipient's node.

To limit this information leakage, Corda provides a facility called confidential identities, which amounts to the secure and verifiable use of one-time pseudonyms. Rather than signing a transaction with a participant's regular long-term key and certificate containing the participant's legal identity, Corda allows for the use of a pseudonymous key and certificate used only for this single transaction.

This mechanism still allows the participants in the transaction to verify it: the confidential identities are transparent to them. At the same time, it no longer allows a later recipient of this transaction, as part of a transaction lineage, to identify the previous participants: the confidential identities are opaque to parties that do not participate in the original transaction.

In the POC, since all settlements are between a participant and the central counterparty and not between two participants directly, all confidential identities are opaque to participants. In this way, the CCP settlement model has the added benefit of improving transaction confidentiality.

This approach provides a good level of confidentiality, but there are some limitations. Over the entire settlement process, each CDS broker-dealer will settle many positions, reusing the outputs of previous settlement transactions. In particular, the cash lineage will become quite long. This allows participants to discover the (anonymized) pledges for all CDS broker-dealers who are to make a net cash payment and a significant portion of the anonymized positions.

An analysis of this information may reveal patterns that allow the linking of anonymized transactions, effectively reducing the level of transaction confidentiality. This information leakage may be reduced by a number of techniques, including reissuance of transactions, use of secure enclaves, and zero-knowledge techniques. The optimal approach is a subject for further study.

04. OPEN QUESTIONS

Jasper Phase III provides insights that lead to further areas of investigation. Framed as open questions, we conjecture that answers to these are essential to any potential future role for DLT-based systems in the Canadian financial market ecosystem.

4.1 SCOPE AND SCALE

A POC is necessarily limited in scope (e.g.instrument types) and scale (e.g. number of participants). Arguably, DLT is an ecosystem rather than application-level technology, and benefits likely accrue as the scope and scale of the ecosystem increase. The following are some areas where further research may determine that the value of DLT is a function of the systems scope and scale.

- Include more aspects of the settlement life cycle. For example, including the trades themselves and performing netting and novation on-ledger may yield benefits in reduced reconciliation costs for participants. Similarly, collateral efficiencies may be demonstrated by including collateral in scope.
- Include additional types of equities activities, such as derivatives trades and securities lending. This would allow participants to manage their business on a portfolio-wide basis instead of asset by asset. The current CDS system permits participants to settle transactions in exchange-traded equities and derivatives, securities lending, and bonds. Expanding the scope of the DLT-based system to include the full spectrum of securities settled at CDS might be required to demonstrate some of the benefits of such a DLT-based system.
- Increase the number of participants and broaden access to include a wider range of participants. Does DLT have a role to play in improving access to FMIs, and could greater access benefit participants, since DLT is a network technology?
- Expand internationally. Would there be significant benefit of expanding the settlement system to also settle the currencies or assets of other countries?
- Consider regulatory issues impacting the proposed DLT model and any expanded international activity, including data privacy, securities, payments, security, financial crime, smart contract, and trade compliance matters.

4.2 BUSINESS MODEL CHANGES

The POC aligned closely with the existing business model and processes for equities settlement. However, DLT enables different business models, potentially including a complete revision of the financial system, due to its decentralized nature. Exploring new business models based on DLT features may prove beneficial. Open questions related to business model changes include the following:

- Consider the option for non-LVTS members to exchange cash between themselves. This is a policy question anchored in the rules governing direct access to the LVTS.
- Consider different and richer credit extension models. For example, an interest- or fee-based model.
- Evaluate settlement models other than a central counterparty. Reassessing this model in a decentralized context requires identifying new ways to offer benefits to participants. Can a decentralized settlement model be designed that removes the need for a CCP without augmenting risk?
- Investigate whether DLT would enable business models that enable or ease introduction of T+0 settlement. For settlement on T+2, there is a preference for a CCP settlement model with the CCP as a guarantor. For T+0 settlement, this preference may change. Can DLT ease or enable such a change? Can DLT support the scalability requirements of such a system?
- Governance structures and processes of systems operated by single entities are mature. Governance of systems that operate across multiple entities, typically consortia, is relatively new. What are the contending governance models for such decentralized systems? What are the benefits and risks with each?

4.3 PRODUCTION READINESS

The Jasper Phase III POC was a true POC, aiming primarily at verification of functional capabilities of the DLT platform and the distributed application implemented on this platform. It paid limited attention to any non-functional requirements, in part because of the short timelines. To evaluate production readiness:

- Expand the POC scope to consider performance, availability, resilience, security, and other non-functional characteristics. Perform exhaustive testing in these areas.
- Include operational models in the scope. For instance, what are the implications of offering components of the system as a service?
- Consider improving resilience by further component decentralization. For example, by using a notary cluster rather than a single notary.

05. CONCLUDING REMARKS

Jasper Phase III successfully demonstrated that a DLT platform can be used for a payment and securities settlement system. The POC platform processed key functions, such as pledging and redeeming cash and equities and performing settlement transactions, in a manner aimed at respecting the privacy and scalability requirements of the Canadian system.

The use of DLT was important for creating a loose integration of the LVTS and CDS that achieved DVP1 settlement with only DVP2 input of liquidity. This loose integration framework left the two authorities involved — the Bank of Canada for cash and CDS for equities — in full control of their respective instruments or tokens.

The platform was also capable of handling the different participant sets between the LVTS and CDS such that each participant was only capable of performing those functions for which they were authorized.

Finally, the project scope was not sufficiently broad to determine whether DLT would yield significant cost savings or efficiency gains. We expect that an expansion of scope across a number of possible dimensions (e.g. multiple assets, more of the trade and post-trade settlement life cycle, and additional types of trades) would provide such insight.

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07. GLOSSARY

Terms	Definition
CCP	Central counterparty clearing acts as an intermediary to mutualize counterparty credit risk by netting and novating transactions between multiple counterparties, and facilitating various risk-mitigation provisions, such as taking collateral deposits and holding guarantee funds
CDS	Canadian Depository for Securities
DDR	Digital depository receipts
DLT	Distributed ledger technology
DVP	Delivery versus payment
DVP1	A system that settles transfers for both securities and funds on a gross basis, with final (irrevocable and unconditional) transfer of securities from the seller to the buyer (delivery) occurring at the same time as final transfer of funds from the buyer to the seller (payment)
DVP2	A system that settles securities transfer obligations on a gross basis, with final transfer of securities from the seller to the buyer occurring throughout the processing cycle, but that settles funds transfer obligations on a net basis, with final transfer of funds from the buyer to the seller occurring at the end of the processing cycle
FMI	Financial market infrastructure
ISIN	International Securities Identification Number
LVTS	Large Value Transfer System
POC	Proof of concept
RTGS	Real-time gross settlement
SSS	Securities Settlement System
Tokenization	The process of converting off-ledger assets into on-ledger assets that can be used to perform DVP settlement

APPENDIXES

The following are appendixes that provide additional information to supplement this white paper.

Appendix A. CURRENT STATE

In scope for Jasper Phase III was the current post-trade equity settlement process for listed equities. This equity settlement process is as follows:

1. TSX matches buyers/sellers, and trades are executed.

2. At 7pm, trade details are sent to CDS via an FTP batch process and no further action is performed by CDS on T+0.

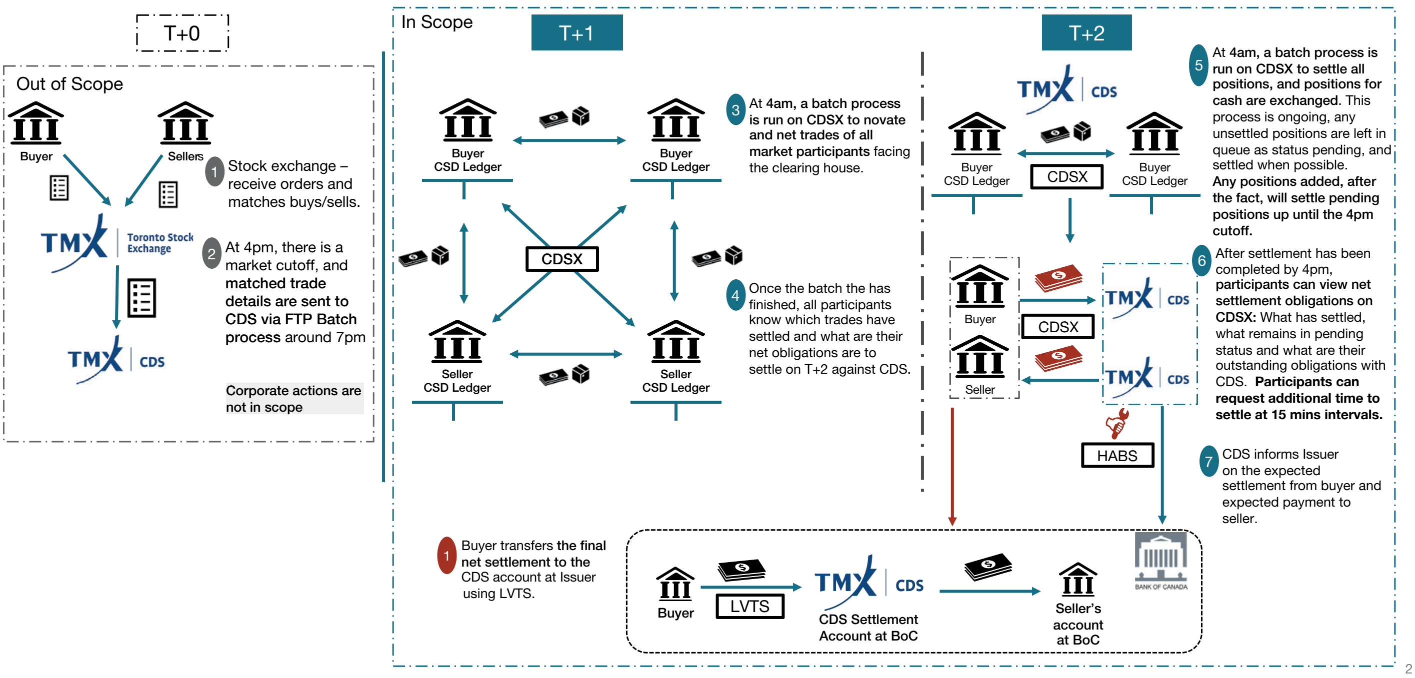
3. At 4am on T+1, a batch process at CDS novates and nets trades for all CDS market participants. At this point, all trade positions are now facing CDS.

4. By 6am on T+1, all CDS market participants can see which positions require additional securities/cash to be delivered (received) to fulfil settlement and what their net obligations are for T+2.

5. At 4am on T+2, a batch process in CDSX attempts to settle all trade positions, and at this point cash and securities are exchanged between buyers/sellers on their CSD ledger. Any unsettled positions remain in pending status up until the 4pm cutoff.

6. Using the High-Availability Banking System (HABS), CDS informs the Bank of Canada on the exchange of cash payments required.

7. Net buyers of securities in CDSX, or their designated banker, make an LVTS transfer to the CDS account at the Bank and net sellers of securities in CDSX, or their designated banker, receive an LVTS payment from the CDS account at the Bank.



Appendix B.
CORDA CONCEPTS

Corda is a DLT platform from R3 that is designed for use with regulated financial institutions. It was used in the Jasper III POC to build the delivery vs payment (DVP) equity settlement system. This appendix provides a simplified explanation of Corda concepts, highlighting how Corda specifies and enforces control over use of assets on-ledger. For a detailed technical description of the Corda platform, refer to the introductory and technical white papers.

A Corda distributed application (CorDapp) is a distributed application installed at the node level that leverages Corda's platform to handle business logic and processes. It consists of four components that jointly determine the capabilities and controls of that application: states, transactions, contracts, and flows.

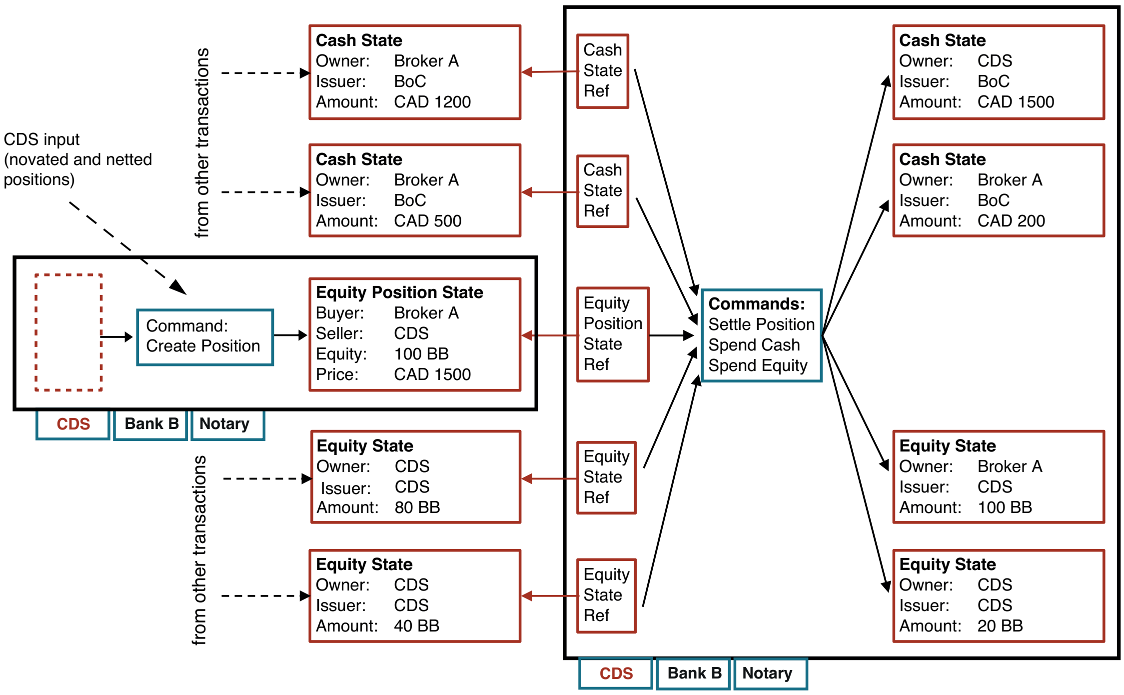
- **States** are immutable on-ledger objects that represent shared facts. Participants that hold a state are in consensus about the contents of that state. In the POC, cash and equity on-ledger are digital depository receipts (DDR), which are represented as a state that fully specifies the DDR, including its current owner.

- **Transactions** are actions, known as commands, on a set of states. Corda has an unspent transaction output (UTXO) model in which a transaction consumes a set of input states (i.e. marks them as historic, or no longer valid) and produces a set of output states, as specified by one or more commands. States are immutable, but transactions offer a way to mark consensus on a change of the facts in the state: it consumes the state with the old values and produces a new one with updated values. For example, to transfer some DDR to another participant, a "spend" transaction would consume a state with the payer as its owner, have one single "spend" command, and produce a new state with the payee as its owner.

  Corda transactions are atomic: they either succeed entirely or fail entirely. For the spend transaction this means that either the payer owns the old DDR, or the payee owns the new DDR. The situation that both DDR states are valid, or that neither of them is, will never happen as a result of this transaction.

  In the POC, a settlement transaction is a slightly more complex transaction that combines three commands: "spend" the cash DDR, "spend" the equity DDR, and "settle" (i.e. just consume) a state representing the position being settled. More precisely, the settlement transaction consumes cash DDR owned by the buyer, equity DDR owned by the seller, and a position describing the position. It produces new DDR states: a cash state owned by the seller and an equity state owned by the buyer.

Atomicity of the settlement transaction implies that either the position remains open (not consumed) and the buyer holds on to the cash and the seller holds on to the equity, or the position is fully resolved: the seller now owns the cash and the buyer owns the equity and the position is no longer open (it is consumed and thus no longer valid).



- **Contracts** specify the rules associated with a state. For example, a cash contract is associated with all cash states and it will specify (among other rules) that a spend transaction cannot change the issuer, increase the amount, or change the currency. A position contract will include rules that ensure that for a settlement transaction, the ownership, amount, and currency of input and output cash, and ownership, quantity, and ISIN of the input and output equity all match the contents of the position.

- **Flows** specify how participants communicate transactions and reach consensus on them.

The issuer of a state determines the contract associated with that state and all its successor states of the same type. Thus, in the POC, the Bank of Canada fully determines the cash contract and CDS fully determines the equity contract. This implies full control by the Bank over all rules applicable to transactions consuming or producing cash.

In the POC, these rules were limited to correctness of the transaction, such as conservation of value. These rules could be extended to limiting transaction types, to requiring or forbidding the participation of certain network participants, or to forbidding certain input or output types or values, among other rules.

The Corda platform provides a network map service that manages and publishes the identities of the nodes on the network. This service can be distributed and run by an independent party.

The notary service of the Corda platform provides a uniqueness and/or validating consensus by attesting to the finality of the transactions. A notary may be a single network node, a cluster of mutually trusting nodes, or a cluster of mutually distrusting nodes. Corda also has a “pluggable” consensus, allowing notaries to choose an algorithm based on their requirements in terms of privacy, scalability, legal-system compatibility, and algorithm agility. In the Jasper III POC, the notary only provides uniqueness consensus.

Appendix C.
EXAMPLE OF THE SETTLEMENT PROCESS

C.1 OVERVIEW

The example below illustrates the settlement process described in Section 5 for a very small set of positions.

The positions are ordered by ISIN and then by decreasing value. The settlement process then attempts to settle each position, in order, skipping any positions where insufficient cash or equities are available. The entire process is iterated until no further positions are settled. In the example, three iterations are needed.

C.2 START

This is the status after pledging cash and equities, just before the start of the settlement process. Participants' cash and equity DDR holdings on-ledger are shown on the left; the list of positions is on the right.

Broker 1	
$	148,893.36
CA001	0
CA020	1275
CA300	0

CDS	
$	167,253.36
CA001	0
CA020	0
CA300	0

Broker 2	
$	0.00
CA001	1303
CA020	2375
CA300	254534

Broker 3	
$	0.00
CA001	800
CA020	0
CA300	0

	Broker	Dir.	ISIN	#	$
1	Broker 1	BUY	CA001	2103	156,547.32
2	Broker 2	SELL	CA001	1301	96,995.32
3	Broker 3	SELL	CA001	800	59,552.00
4	Broker 3	BUY	CA020	3650	26,280.00
5	Broker 2	SELL	CA020	2375	17,100.00
6	Broker 1	SELL	CA020	1275	9,180.00
7	Broker 1	BUY	CA300	25434	1,526.04
8	Broker 2	SELL	CA300	25434	1,526.04

Positions ordered by ISIN and then value

The cash and equity holdings on-ledger of the brokers are exactly their net obligations for the entire settlement process.

Note that CDS has an initial balance slightly larger than the largest transaction. This is required in this very simple algorithm to kick-start the process (all positions are against CDS, so no individual position can settle unless CDS holds either sufficient cash or sufficient equity).

C.3 ITERATION 1, EQUITY CA001

Broker 1	
$	148,893.36
CA001	0
CA020	1275
CA300	0

CDS	
$	10,706.04
CA001	2301
CA020	0
CA300	0

Broker 2 sells 1301 CA001 for $96,995.32

Broker 2	
$	96,995.32
CA001	0
CA020	2375
CA300	254534

Broker 3 sells 800 CA001 for $59,552.00

Broker 3	
$	59,552.00
CA001	0
CA020	0
CA300	0

	Broker	Dir.	ISIN	#	$
1	Broker 1	BUY	CA001	2103	156,547.32
2	Broker 2	SELL	CA001	1301	96,995.32
3	Broker 3	SELL	CA001	800	59,552.00
4	Broker 3	BUY	CA020	3650	26,280.00
5	Broker 2	SELL	CA020	2375	17,100.00
6	Broker 1	SELL	CA020	1275	9,180.00
7	Broker 1	BUY	CA300	25434	1,526.04
8	Broker 2	SELL	CA300	25434	1,526.04

Position 1 cannot settle: CDS does not have equity

The position and balance in green are executed. Position 1 is not executed, as Broker 1 does not own sufficient cash to settle this position.

Positions now settled are greyed out.

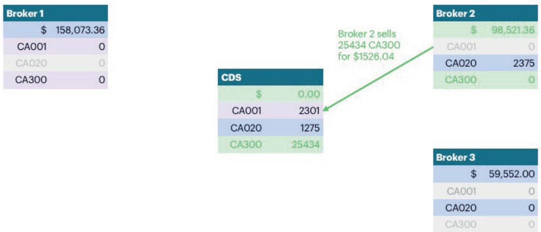
C.4 ITERATION 1, EQUITY CA020

	Broker	Dir.	ISIN	#	$
1	Broker 1	BUY	CA001	2103	156,547.32
2	Broker 2	SELL	CA001	1301	96,995.32
3	Broker 3	SELL	CA001	800	59,552.00
4	Broker 3	BUY	CA020	3650	26,280.00
5	Broker 2	SELL	CA020	2375	17,100.00
6	Broker 1	SELL	CA020	1275	9,180.00
7	Broker 1	BUY	CA300	25434	1,526.04
8	Broker 2	SELL	CA300	25434	1,526.04

Positions 4 and 5 cannot settle: CDS does not have equity and cash, respectively.

Positions 4 and 5 cannot settle, as CDS does not have the equity and cash required, respectively. Position 6 does settle successfully, as Broker 1 owns the equity and CDS has sufficient cash.

C.5 ITERATION 1, EQUITY CA300

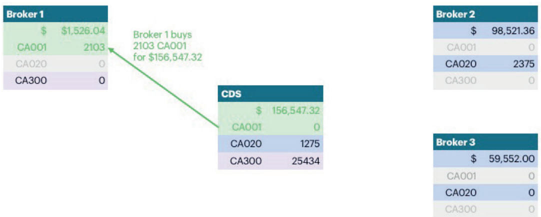


	Broker	Dir.	ISIN	#	$
1	Broker 1	BUY	CA001	2103	156,547.32
2	Broker 2	SELL	CA001	1301	96,995.32
3	Broker 3	SELL	CA001	800	59,552.00
4	Broker 3	BUY	CA020	3650	26,280.00
5	Broker 2	SELL	CA020	2375	17,100.00
6	Broker 1	SELL	CA020	1275	9,180.00
7	Broker 1	BUY	CA300	25434	1,526.04
8	Broker 2	SELL	CA300	25434	1,526.04

Position 7 cannot settle: CDS does not have equity

Note that CDS has completely drained its cash balance but holds many equity positions.

C.6 ITERATION 2, EQUITY CA001



	Broker	Dir.	ISIN	#	$
1	Broker 1	BUY	CA001	2103	156,547.32
2	Broker 2	SELL	CA001	1301	96,995.32
3	Broker 3	SELL	CA001	800	59,552.00
4	Broker 3	BUY	CA020	3650	26,280.00
5	Broker 2	SELL	CA020	2375	17,100.00
6	Broker 1	SELL	CA020	1275	9,180.00
7	Broker 1	BUY	CA300	25434	1,526.04
8	Broker 2	SELL	CA300	25434	1,526.04

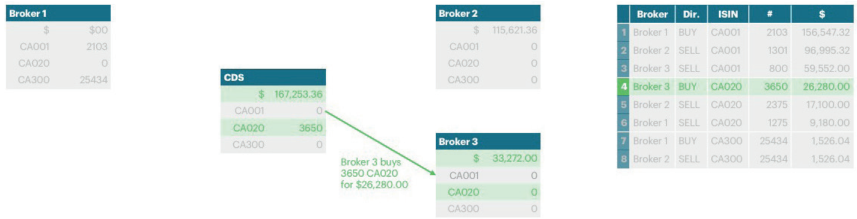
C.7 ITERATION 2, EQUITY CA020

	Broker	Dir.	ISIN	#	$
1	Broker 1	BUY	CA001	2103	156,547.32
2	Broker 2	SELL	CA001	1301	96,995.32
3	Broker 3	SELL	CA001	800	59,552.00
4	Broker 3	BUY	CA020	3650	26,280.00
5	Broker 2	SELL	CA020	2375	17,100.00
6	Broker 1	SELL	CA020	1275	9,180.00
7	Broker 1	BUY	CA300	25434	1,526.04
8	Broker 2	SELL	CA300	25434	1,526.04

Position 4 cannot settle: CDS does not have equity

C.8 ITERATION 2, EQUITY CA300

C.9 ITERATION 3



C.10 END RESULT

All positions have now settled. Note how:

- Brokers 1 and 3, who started with a zero-cash balance, now have a positive cash balance.
- Broker 2 started with positive cash (its net amount due) and now has a zero-cash balance.
- CDS has the same cash balance as at the start.
- For each equity, Brokers either have a zero balance at the start or at the end. CDS has a zero balance both at the start and at the end.

A different order of execution may reduce the amount of initial cash required at CDS, and more sophisticated algorithms (e.g. settling multiple positions in one atomic transaction) could remove this requirement altogether.

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