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Settlement risk in cross-border transactions: traditional and new approaches

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Abstract

Although the wholesale payment systems operate unnoticed daily, these arrangements are crucial for our daily life. In this thesis I attempt to shed more light on the settlement risk in traditional wholesale payment systems based on corresponding banking (CB) settlement, and the Continuous Linked Settlement (CLS) systems, and a new settlement system based on the Distributed Ledger Technology (DLT). The contemporary systems for cross-border payments are complex, costly, and fragmented, so, many companies and authorities are searching for a more viable solution to take advantage of modern technology, and for creation of a safe and efficient payment system. It is necessary to improve the interoperability among the local and global financial infrastructures in order facilitate and evolve international trade and development for all countries.

This thesis presents extended literature and computational analyses of the settlement risk duration and exposure for a simple high-value payment and FX spot deal between small-size financial institutions or corporates. The settlement based on the CB network, settlement via the CLS system, and the DLT-based settlement using Utility Settlement Coin (USC) are the main study objects.

The analysis results demonstrate that the settlement system based on CB expose its customers to a considerable settlement risk due to low transparency, tied-up liquidity, and time-consuming manual processes. The CLS system allows reducing the settlement risk for its direct participants, but the third parties are still face significant settlement risk exposure due to the linked CB parts.

This work demonstrates the a USC settlement system can alleviate the settlement risk by means of faster settlement (0.5-8 hours instead of 5-24 hours), end-to-end visibility, and greater trust in the time-critical and reliability-demanding wholesale cross-border payment system. The settlement delays in the USC-based system are mainly associated with overburden regulatory compliance checks and direct participants' desire to delay the final transfer in order to optimize the liquidity usage through the day.

Contents

List of abbreviations

ACSS	Automated Clearing Settlement System
AML	Anti-Money Laundering
API	Application Programming Interfaces
BIC	Bank Identity Code
BIS	Bank of International Settlement
B2B	Business-to-Business
B2C	Business-to-Consumer
CB	Corresponding Banking
CBDC	Central Bank Digital Currency
CET	Central European Time
CHAPS	Clearing House Automatic Payment System
CLS	Continuous Linked Settlement
CSM	Clearing and Settlement Mechanism
CTF	Counter-Terrorism Financing
C2C	Consumer-to-Consumer
DDR	Digital Depository Receipt
DL	Distributed Ledger
DLT	Distributed Ledger Technology
DNS	Differed Net Settlement
DvP	Delivery-Versus-Payment
EBA	Euro Banking Association
ECB	European Central Bank
ECU	European Central Unit
FED	Federal Reserve
FX	Foreign Exchange
G2C	Government-to-Consumer
GDPR	General Data Protection Regulation
HTLC	Hashed Timelock Contracts
IBAN	International Bank Account Number
IOU	I owe you
IP	Internet Protocol

IPIC	Initial Pay-in Schedule in CLS
IT	Information Technology
I/O	Inside/Outside Swap in CLS
KYC	Know Your Customer
LSF	Liquidity Saving Feature
LSM	Liquidity Saving Mechanism
MN	Multilateral Netting
NBO	Norges Bank' Settlement System
RPIS	Revised Pay-In Schedule
PvP	Payment-versus-Payment
PoW	Proof-of-Work
RTGS	Real-Time Gross Settlement
SEPA	Single Euro Payment Area
SHA	Secure Hash Algorithm
SME	Small- and Medium-Sized Enterprises
SWIFT	Society for Worldwide Interbank Financial Telecommunication
TARGET	Trans-European Automated Real-Time Gross Settlement Express Transfer
T2S	Target to Securities
US	United States
USC	Utility Settlement Coin

1. Introduction

Technological innovations and globalization demand the financial and payment infrastructure to develop. A lot of fintech solutions have appeared in the market in recent years. These solutions are reducing complexity and costs within financial infrastructure, providing better transparency in transactions and improving access to a greater number of customers (Chapman et al., 2017). International payments and assets transfer are fields where structural changes are needed the most as they are vital for trade, finance, and other economic interactions (Szmukler, 2017). The volume of global payments is increasing at rate of 5% yearly, where the highest rate is seen in the US, the EU, Asia, and Brazil (McWaters et al., 2016). The foreign exchange (FX) market had daily turnover of US$ 5.1 trillion in 2016 (Mustish, 2016). The business-to-business (B2B) segment is seen as the most growing in the recent years, as small- and medium-sized enterprises (SMEs) operations expand with consequences as higher trade volumes and "supply chain fragments" (Denecker et al., 2016). In accordance with the report by Capgemini (2016) the banks have controlled overall about 90% of the total payment volume in 2015. However, this share is reducing due to crucial changes in the customer needs and new fintech offerings (Manchiraju et al., 2016).

The payment industry has faced several disruptive changes in recent years. The use of cash is reducing in many countries due to technological developments, changes in consumption factors, and access to new technologies (Chapman et al., 2017). Another key dynamic factor is real-time payments. Online commerce increases customer requirements for real-time payments and easy electronic payment solutions. The new daily life of customers and business produces their expectations to have the international payment to be as efficient and real-time as domestic ones. The next challenge is structural changes in financial infrastructure thanks to new technologies, regulatory requirements, and behavior aspects, such as DLT, Open Application Programming Interfaces (API), mobile payments etc.

1.1 Money and international funds transfer

Money presents a claim on local central bank and, therefore, they are assumed liquid, neutral to market participants, safe (no credit risk), efficient, and service continuity. In the modern economy the money is presented by a bank deposit (97%) and currency/cash. The cash can be assumed as decentralized money, while bank deposits or virtual money are controlled by central bank through centralized settlement and clearing. Monetary policy provided by central bank is targeting to control or limit the amount of created money in order to support stability in the economy. It is done primary through setting interest rate on bank reserves, injection/withdrawal of liquidity, or purchasing assets (quantitative easing) when the effective lower bound of the interest rate is reached (McLeay et al., 2014). Well-functioning settlement system of payments allows the central bank to transmit or execute its monetary policy, prevent systematic risks, and support public trust in the currency. The settlement of payments can be done immediately in cash or via central bank accounts. (Kokkola et al., 2010; McWaters, 2016; Nakaso, 2017)

Central bank core tasks consist in supporting a payment standard and supplying the payment system with a payment asset free of default risk. (Noël, 1993; Chapman et al., 2017). In practice these targets are fulfilled through supplying the countries with coins and banknotes, an arrangement for central bank gross settlement, supporting efficient and safe payment system through oversight processes and banks supervision (Patrikis, 1995). The access to account-based central bank money (or digital money) is limited to banks and several financial institutions, while cash or physical central bank money is accessible widely. This way the central bank supports the functioning of the economy, and thereby the welfare of society. However, public direct access to Central Bank money become more complicated recently, as the use of cash is decreasing in many countries (Lober and Hauben, 2018).

Efficient and safe payment system is supported by the central bank through centralized settlement of the payments in account-based money or digital money held within central bank (see Fig. 1.1). The commercial banks, government, foreign central banks, international financial institutions, securities firms, and clearing houses hold accounts at the central banks to settle the final large-value money transfers with the counterparties.

The wholesale payments are usually time-critical. Therefore, stable, robust, and fast functioning of the payment system is essential for financial institutions and overall financial stability. The intra-day settlement by central bank is assumed as safest, efficient, neutral, and final. In this way, the central bank is acting as an operator and oversight authority which provides account and settlement services to transfer the funds, and, thereby, ensures the safety and efficiency of important payments. However, only a limited number of financial institutions have direct contact with the Central Banks, as it requires investments (eligible collateral) in the operational facilities. The eligible collateral should be held within the

Central Banks to get intraday and overnight loans or liquidity. This ensures avoiding of the liquidity risks. The financial institutions without a direct contract with the Central Banks use the services of intermediaries or the money market in order to settle and clear their payments (Lober and Hauben, 2018; Kokkola et al., 2010).

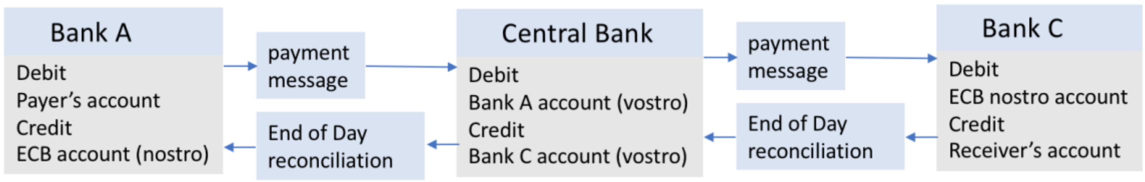


Figure 1.1: ECB payment system settlement
Source: Author's own illustration created based on (Kokkola et al., 2010)

Payment systems differ considerably from country to country due to inconsistencies in regulatory, legal, and institutional environments of these countries (Noël et al., 1993; Allsopp et al., 2009). Several wholesale and retail settlement systems are listed in Table 1.1. Before 1980s, all central bank settlement systems were based on Deferred Net Settlement (DNS), where settlement of transactions was deferred until their aggregation into batches and consequently netted into single payments at regular times through the day. However, the net settlement exposed the participants to systemic and liquidity risks in case of failure of even one participant. (Kokkola et al., 2010)

Nowadays most of the central bank systems (Fedwire in the US, Clearing House Automatic Payment System (CHAPS) in the UK, TARGET2 in the EU) are based on Real-Time Gross Settlement (RTGS). Several private settlement systems (EURO1, CHIPS) are based on Multilateral Netting (MN) of payments. This change was associated with increased settlement and systemic risks in growing financial markets with higher volume and values of the netting transactions and stricter time requirements (Impenna and Masi, 1997; Kahn et al., 2014). The MN-based arrangements settle the payer and receiver obligations on a net basis or by building up the positions in order to reduce the liquidity requirements. However, the netting process exposes the participants to credit risks. The RTGS system processes every payment "individually, immediately and with finality throughout the day" (Garratt, 2014). The payments are settled on the basis of prefunded positions or the liquidity pool collected from the participants. These conditions require higher liquidity for participants, but their exposure to settlement and intraday credit risks is kept low. (Mills and Nesmith, 2007; Kokkola et al., 2010; Chapman et al., 2017).

Table 1.1: Settlement systems

Source: ECB, 2018; FR, 2018; BIS,2018

	Number of settled transactions	Value of transactions	Number of settled transactions	Value of transactions
	2013		2017	
TARGET2	91.3 million	€ 559.7 trillions	90.3 million	€ 485.8 trillions
Fedwire	134.2 million	$ 713.3 trillions	153.2 million	$ 740.1 trillions
CLS	205.0 million	€ 897.1 trillions	198.5 million	€ 1 192.6 trillions
- EUR	36.9 million	€ 182.3 trillions	34.0 million	€ 219.9 trillions
- DKK	0.5 million	€ 7.4 trillions	0.7 million	€ 7.7 trillions
- SEK	2.8 million	€ 12 trillions	3.7 million	€ 17.6 trillions
Euro1	64.1 million	€ 48.7 trillions	53.0 million	€ 42.6 trillions
CHIPS	103.1 million	$ 380 trillions	112.5 million	$ 393.2 trillions

In accordance with the European Central Bank (ECB) report, all the sent transactions in the CLS systems are credit transfers. As it is seen from Table 1, the share of CLS in the settlement of the transactions in EUR increased from 32.6% to 45.3% from 2013 to 2017. As it is seen, more than half of EUR transactions are still settled through CB or other facilities.

To participate in the central bank RTGS systems the participants should meet several requirements and pledge a collateral to achieve intraday and overnight credits from the Central Bank. For example, the participants of the Trans-European Automated Real-time Gross Settlement Express Transfer (TARGET2) system keep about 8% of their daily settlement turnover at the ECB accounts. The amounts tied up for the clearing and settlement systems in the central banks' settlement systems do not generate any interest. Therefore, many small- and medium-sized financial institutions prefer to use intermediaries to clear their payments. The Liquidity Saving Feature (LSF), hybrid systems and overdrafts are applied in many settlement systems in order to reduce the liquidity needs of participants in the RTGS systems. The LSF allows matching the offsetting payments periodically in order to settle only net obligations of the parties. The participants of these settlement systems can also overdraw their reserve accounts in case of insufficient reserve in order to settle their payment obligations. Before 1995 the daylight overdraft credits were offered free of charge by some central banks, for example, by the Federal Reserve (FED) in the Fedwire (Gilbert, 1989). However, the free of charge overdrafts led to the exposure of the Central Bank to the credit risk, so nowadays the intraday and overnight overdrafts are offered at a relatively inexpensive rate. The RTGS systems are applied mainly by big financial institutions for large and urgent payments due to their high service fees and interest loss associated with the required collateral in comparison with other settlement systems (Table 1.2). (Mills and Nesmith, 2007; Kokkola et al., 2010; Garratt, 2014; Chapman et al., 2017)

Cross-border payments are settled mostly on a non-payment-versus-payment (PvP) base or mechanism, where settlement parties are debited and credited not simultaneously on two accounts (Noël, 1993). The non-PvP settlement and inconsistencies in the payment arrangements of many countries result in less robust, slow, and complex transfer process for the international payments. The money transfer can take several days to be settled between two banks today, as often these banks do not have reciprocal accounts. As central bank money is limited to its local area of jurisdiction and thereby each central banks RTGS system is able to settle only one currency, the financial institutions apply other settlement institutions or Vostro banks to arrange the payments in multiple currencies. For this reason, the interbank fund transfer systems based on CB or intermediary payment system are the most common ways to settle the cross-border payments between financial institutions today. In these arrangements the financial institutions or banks are connected to the clearing and settlement of foreign central banks through direct participants' services or local banks, as shown in Fig. 1.2. (Kokkola et al., 2010)

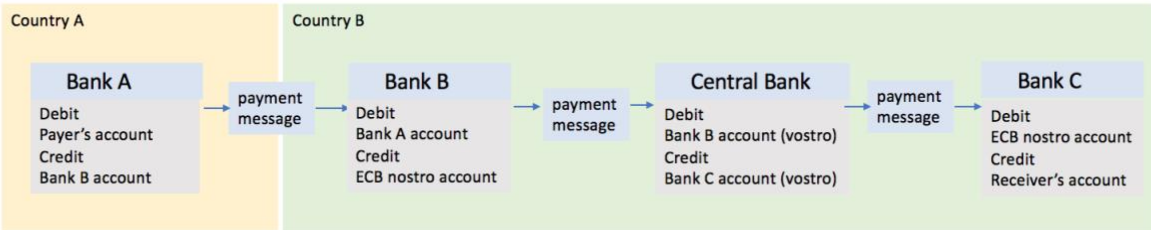


Figure 1.2: Settlement through correspondent bank B
Source: Author's own illustration created based on (Kokkola et al., 2010)

The cross-border trades via traditional arrangements of correspondent banks are prone to the settlement and principal risks during several hours or days, as the settlements of two currency legs are difficult to synchronize in two central banks' payment systems due to different operating times, technical and legal reasons. Some part of FX trades is settled also by on-us settlement mechanism where both currency legs are settled in the books of the same bank or branches of the same bank (Arjani, 2007).

Since 2002 the foreign currencies fund transfer started to be settled in the CLS system. This private institution was launched in order to reduce the described above foreign exchange settlement risks. The CLS utilizes a PvP settlement of foreign exchange transactions through its members' accounts on its books. CLS Bank International has access to central banks funds in 18 operated currencies via the large-value payment systems of correspondent countries. Only shareholders of CLS and user members of the CLS system are allowed to be settled. The other parties are connected to settlement as third parties or Nostro agents through the first two groups. The central banks’ large-value payment systems and CLS system interact for eligible currencies to address the foreign exchange risks by using the PvP settlement, so the members of the CLS benefit from this netting. However, the conducting a foreign transaction via the CLS system requires higher liquidity and it is more expensive than using central bank money. (Kokkola et al., 2010; Kahn et al., 2014)

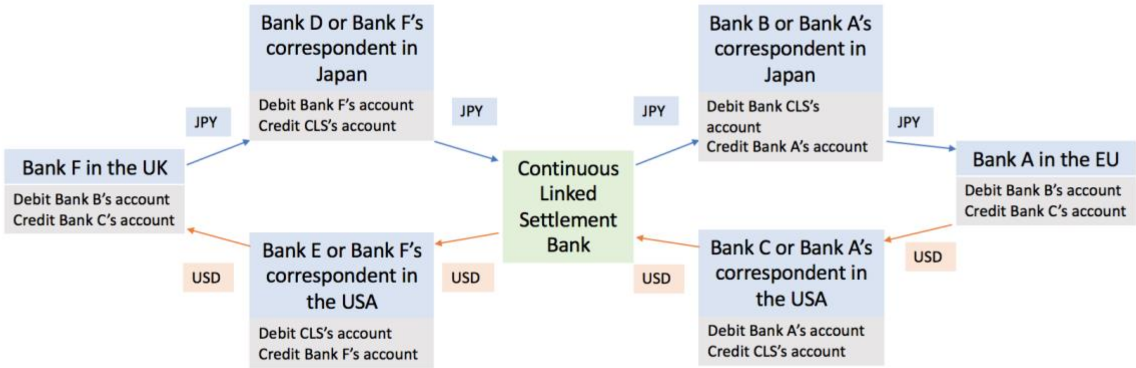


Figure 1.3: Settlement through CLS
Source: Author’s own illustration created based on (Mägerle and Maurer, 2009)

Payment systems of the European Union

Before introduction of euro in 1999, the main way to handle large-value cross-border payments in Europe was CB. A group of European Union-based banks applied the European Central Unit (ECU) Clearing System to process financial and commercial transactions denominated in a virtual basket of currencies (ECU) and to settle them at the Bank of International Settlement. After 1999 the EURO1 system replaced the ECU-based settlement system. Today the ECB utilizes the TARGET2 system to settle cross-border large-value euro transactions in central bank money in the Eurozone. The Single Euro Payment Area (SEPA) has been launched in 2008 to handle retail payments in euro. (Kokkola et al., 2010)

TARGET2 represents the core system for the financial institutions liquidity management which accounted for 89.4% market share in terms of value, and 60.3% market share in terms of volume in 2009. It utilizes the Single Shared Platform to handle the payments from 7a.m. to 6 p.m. and from 7.30 p.m. to 6.45 a.m. Central European Time (CET) at working days. TARGET2 presents RTGS system where transactions are settled one by one with immediate finality by the Eurosystem. This settlement is unconditional and irrevocable, as the account of the sender is always debited first and, therefore, no credit or liquidity risk for the parties appears. TARGET2 system is preferred mostly for urgent payments due its expensive pricing and high opportunity cost of the required collateral compared to the other settlement systems (Table 1.2). The TARGET2 members are keeping about 8% of their daily average aggregated value of payments as a deposit within the Eurosystem. All financial institutions with clearing accounts at their domestic central banks within the Euro area are direct members of TARGET2. The direct participants of TARGET2 are only supervised credit institutions which were 800 in 2009. The foreign financial institutions are connected to TARGET2 via their branches in the Euro European Union or correspondent parties. (Padoa-Schioppa, 2004; Kokkola et al., 2010; Berndsen and Heijmans, 2017; Coppola, 2018)

Table 1.2: Pricing in the EU settlement systems

Source: ECB, 2017; EBA Clearing, 2018;

	Entrance fee	Option 1		Option 2		Additional costs
		Monthly fee	Transaction fee	Monthly fee	Transaction fee, volume-based	
TARGET2		€150	€0.80 per transaction	€1,875	€0.20-0.125 per transaction	-
EURO1	€30,000	Annual fixed transaction fee applied based on transaction volume during year			€0.04-0.32 per transaction	Exit fee, contribution to a liquidity pool (deposit held with the ECB)

The second-biggest euro-denominated net settlement system is the Euro Banking Association (EBA) CLEARING Company's EURO1, which evolved from the ECU-based settlement system. It operates from 7.30 a.m. to 4 p.m. CET and settles the final positions of the members at TARGET2 in central bank money at the end of the day. The EURO1 was set-up by the EBA with 190 member banks. The clearing members of the EURO1 are subject to certain criteria, such as certain amount in own funds, registered office in the EU, connection to TARGET2 and adequate operational facilities. The transactions in EURO1 are settled on MN principle and supported by the Society for Worldwide Interbank Financial Telecommunication (SWIFT) messaging that represents the common language for international financing messaging (Lacity and Ross, 2018). It processes transactions and balances using certain liquidity management tools, such as a system of debit and credit limits per each member and liquidity pool held at the ECB member. EURO1's processing infrastructure is applied to calculate the single obligation for each member at the end of the operating day. The system accounted for 4.3% market share in terms of value and 20.2% market share in terms of volume in 2009. In 2006 the EURO1 and TARGET2 have launched the liquidity bridge between them to improve the payment capacity by shifting it between the systems at a pre-funding and a distribution phase. (Kokkola et al., 2010)

The retail payment systems in the Europe are presented by national retail systems - Euro1, Euro2, and the SEPA system. All less time-critical retail payments are settled through these systems (Coppola, 2018). The SEPA system is operating based on the commonly accepted principles - credit transfer using International Bank Account Number (IBAN) and Bank Identity Code (BIC), and UNIFI XML message standards, direct debit scheme, and payment cards framework. The transactions are settled through arrangements of several SEPA-compliant clearing and settlement mechanisms (CSMs) connected at one side to TARGET2 system and at another side to the remitting or receiving financial institutions. The funds are totally handled inside the TARGET2 system (Fig.1.4).

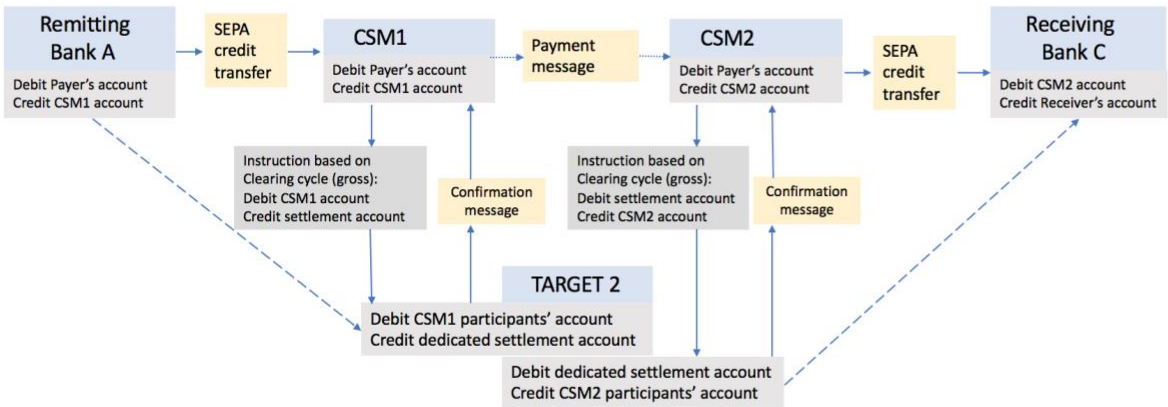


Figure 1.4: EU payment system settlement
Source: Author's own illustration created based on (Kokkola et al., 2010)

1.2 International payments via corresponding banking

An increase in international trade, globalization, and technology in the last century resulted in a huge network of correspondent payments (Folkerts-Landau et al., 1997). It is associated with the fact that financial corporations and organizations without commitments with each other are lacking trust necessary in fund transfer operations (Brennen and Lunn, 2016).

Correspondent Banking (CB) presents a process where one financial institution carries out payments on behalf of another financial institution due to no local presence of the first one or its desire to avoid the liquidity requirements in the RTGS systems (Nielsen, 2005; Denecker et al., 2016). This service is based on bilateral private contractual arrangements, or arrangements with an intermediary, or a third-party service provider. In this way the financial institutions forward their clients payment instructions to an intermediary (correspondent) for processing using their accounts (Vostro or Loro account) in the books. The big correspondent banks keep thousands of Vostro accounts in their books for smaller banks to provide an opportunity for them to perform their transactions internationally. In accordance with McKinsey analysis (2017), the global payments account for 34% of overall banking revenue and will have average growth of 7% for the next 5 years. The CB accounts for 50% of transaction services' revenues while it presents only 20% of the transactional volume for the financial institutions in 2015 (Niederkorn et al., 2016; Denecker, 2017).

The customer banks have Nostro accounts to settle the payments with the service-provider or correspondent bank. The sender bank should originate the payment in local currency of the receiving bank, so the funding is affected by a foreign exchange exposure. The trust channel between two banks allows accepting I owe you (IOU) and settle the balances periodically (Kokkola et al., 2010). The international financial messaging system SWIFT is used to instruct transactions between the financial institutions. The SWIFT messages include customer payments message (MT103), financial payment message (MT20x), reporting messages (MT950, MT940) and others. The described set-up is shown in Fig. 1.5. It presents the serial method of cross-border payment transfer, where the Bank A and D do not have SWIFT bilateral arrangements and, therefore, the series of SWIFT MT103 payment instructions is sent along the chain of the CB. The serial method is slower than the cover method of cross-border payment transfer when the Bank A can send the SWIFT MT103 message straight to the receiver Bank D and the SWIFT MT202 (MT202COV) to its correspondent Bank C (KPMG, 2018).

The CB relationships are playing an essential role in the world economy, as they enable international payments for small financial institutions and companies. However, many experts describe this type of fund transfer as "messy, slow, and costly" (Lacity and Ross, 2018). The CB route has endogenous fixed costs (capital lockups, guarantees), as the Nostro accounts require to hold funds which do not generate any interest. The correspondent accounts impose also huge costs on both parties, as their outstanding funds need to be monitored, controlled, and reconciled (Szmukler, 2017). The operational time of fund transfer is often uncertain to the sender and the receiver, so they are exposed to credit risks in

CB transactions. These uncertainties, risks, and high cost of CB fund transfer have leaded to lesser number of such transactions over recent years and proliferation of PvP systems through the trusted third parties (such as the CLS system and other payment systems). The netting arrangements allow reducing the counterparty risk, liquidity, and settlement costs. The inefficiency and high costs of CB have supported the success of non-bank parties, such as PayPal, TransferWise and Western Union. These money transfer services offer better transparency, predictability, convenience, and ubiquity, especially for customer-to-customer payments. (Nielsen, 2005; Kokkola et al., 2010; Denecker et al., 2016)

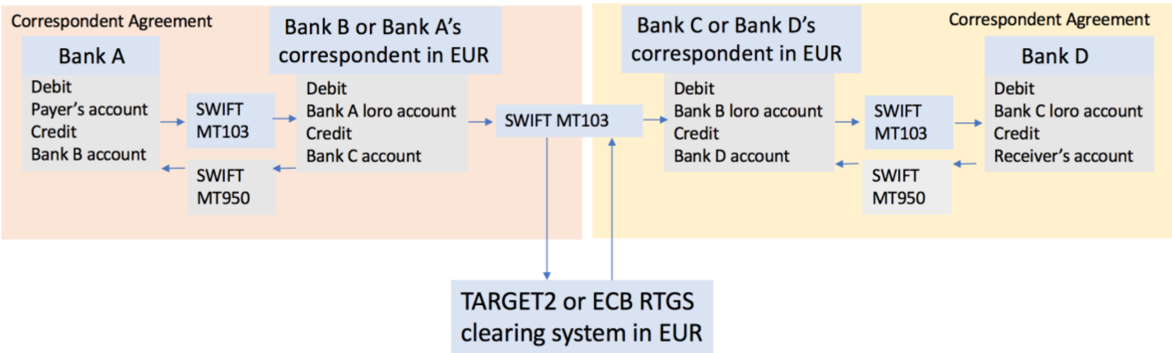


Figure 1.5: Corresponding payment system settlement
Source: Author's own illustration created based on (Miller, 2002; Kokkola et al., 2010)

However, the CB is still a very important channel of the cross-border fund transfer due to several reasons. The first of them is a lack of relevant payment arrangements for some types of transaction, such as payments in illiquid currencies. Secondly, the CB allows a connection or indirect access to foreign payment systems, especially for foreign fund transfers, small- and medium-sized banks and SMEs. The third reason is considerations related to operational risk management or contingency. The next reason is an inability of small- and medium-sized financial institutions to meet strict access criteria for direct participating in the central bank settlement system. The fifth reason is a security of CB payment. The openness and compliance can be named as another reason to choose legal CB fund transfer instead of the non-bank services. Yet another reason is inclusivity of CB offer to big corporations which requires unique services. It allows providing relationship banking and achieving profits via value-added services. (Denecker et al., 2016)

Commonly a payment process consists of three elements – payment, processing and settlement (Kokkola et al., 2010). The current state of the global payments is illustrated in Fig.1.6. The common non-cash cross-border payment is described by 6 steps by the specialists on the World Economic Forum (McWaters, 2016). At the first step (1) the sender bank or money transfer operator needs to collect and validate the transfer instructions (account number, BIC), funds and fees, perform the necessary regulatory compliance checks, and support transfer inquiries. This step is associated with a lot of manual and technical efforts to establish legal and technical validity, checks for the fund availability, preparations of the payment instructions, and providing the entities for the customer account. The regulatory compliance check is prone to a limited control over supportive documentation that often leads to inconsistency and, therefore, frictions at the first step of the cross-border funds transfer (McWaters, 2016).

At interbank processing part of the payment process, the sender bank supports the funds transfer through an intermediary clearing-house based a CB (2b) or payment system, for example the Society for SWIFT network or Central Bank for large-value payments (step 2a) (McWaters, 2016; Biella and Vittorio, 2016). This step includes confirmation, transmission, reconciliation, netting, and facilitation of the final positions for the further settlement (Kokkola et al., 2010). The SWIFT network enables the exchange of secure transaction messages (not the funds) via Internet Protocol (IP) links between the banks in real time. The Central bank's settlement system operates only in local currency, so the services of a central settlement institution or settlement agent are applied to settle the multicurrency operations (Kokkola et al., 2010; Szmukler, 2017).

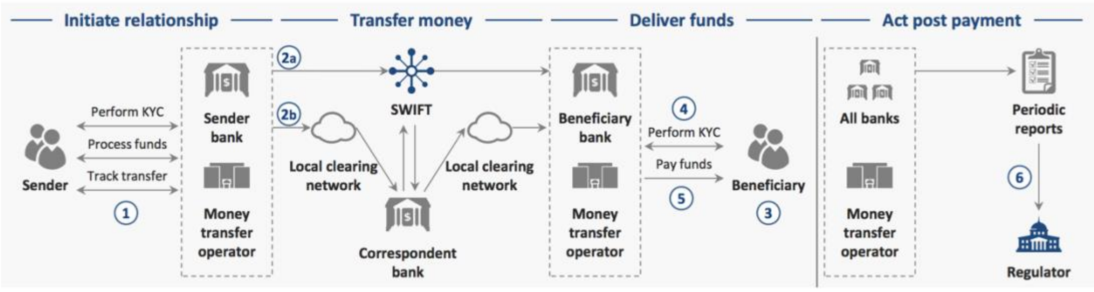


Figure 1.6: Inter-banks payment system
Source: McWaters et al., 2016

As third and fifths steps in Fig. 1.6 or settlement part of the payment process, the parties discharge their obligations or crediting/debiting the sender/receiver accounts. The clearing procedure consists in defining the transaction counterparties obligations to perform the delivery at the agreed conditions. The settlement in international payments is relying on a settlement agent, which is usually a payment system operator or the central bank. The beneficiary banks or the money transfer operator receives the funds that is considered as an irrevocable and unconditional transfer (with settlement finality). The settlement process can be based on gross vs net settlement, and real-time vs designated-time settlement.

In step 4 (Fig. 1.6) the receiving bank or a money transfer operator approaches the beneficiary of the transfer to pay it due after the internal processing and regulatory compliance checks for the beneficiary. This process is vulnerable again to a limited control over supportive information (Kokkola et al., 2010). The compliance process (step 6) between the financial institutions and the regulator is performed as a post payment step. It is a very costly process, as the money transfer operator should deliver the report with all the required transaction details (legal IDs, amounts, timestamps) which are coming from many sources and originations of the complex international payment system. The post-settlement of the CB fund transfer includes also reconciliation process between the Nostro and Vostro accounts of the involved parties and asset servicing. The reconciliation process is additionally complicated by differences in standards, for example payments messages. Moreover, the reporting activities are also subjected to local regulation frameworks and requirements. (McWaters, 2016; Löber et al., 2017)

1.3 Foreign Exchange transactions via CLS

FX market has grown a lot in the latest decades and became the most liquid market with daily average trading value USD 5.1 trillion in 2016 (CLS, 2017). Table 1.3 summarizes the global FX daily turnover in USD, EUR and SEK based on the Bank of International Settlement (BIS) report (2016). CLS system was established in 2002 to minimize settlement, credit, liquidity, replacement, and systemic risks in foreign exchange payments associated to time differences in local central clearing systems of the correspondent local currencies. Many authors name the closure of Bankhaus Herstatt in 1974 as the main trigger to create CLS for multicurrency settlement and clearing (Miller, 2002). CLS payment system includes CLS Bank International and CLS Services. CLS Bank International is responsible for accounts management and it is regulated by the FED. CLS Services provides operational, technical, and Information Technology (IT) back office services. In 2018 the CLS system offered services in 18 main currencies and supported 68% of all trades in these currencies. The currency is included in the CLS settlement only when it meets special requirements, such as appropriate legal foundations for payment finality, convertibility and exchange conditions, operation of country’s RTGS system and access to it, low country risk. Due to these strict requirements, the CLS settles only around half of all FX transactions in the world. (Mägerle and Maurer, 2009; Kambayashi, 2013)

Table 1.3: Global FX turnover in absolute value
Source: BIS Survey, 2016

daily average in billions USD	1988	2004	2010	2013	2016
USD	1 325	1 702	3 370	4 661	4 458
EUR	-	724	1 231	1 789	1 591
SEK	5	42	87	94	113

In 2017 CLS had 66 direct members and more than 4500 indirect members or third parties. The direct members should be shareholders of CLS Group Holding and must meet strict requirements, such as operational and financial standards, adequate supervision, credit ratings, compliance with Anti-Money Laundering (AML) and screening (not on sanctions list) requirements, access to liquidity facilities, etc. The direct members are settled through their accounts presented by different currencies sub-accounts in the CLS bank. (Mägerle and Maurer, 2009; Mustich, 2016)

The average cycle of the CLS settlement is illustrated in Fig. 1.7. The CLS gets the payment details or instructions by means of the SWIFTNet InterAct messages from the direct participant or indirect participants via a third-party service of the direct participant. These instructions should be sent by 00:00 CET before the value date of the transactions in question, so the CLS can validate, match, and store them before the gross settlement starts at 07:00 CET. The CLS system settles the instructions individually (or on gross basis) while it nets the resultant payment obligations assuming that all the submitted transactions will be settled on the relevant settlement date. The netting of the resultant payment obligations allows reducing the required funding by 95% of the trades' gross value. The CLS system splits the large value payment instruction into smaller payments in order to process them more efficiently. This settlement of the transactions is finalized at 09:00 CET. (Sweet et al., 2007; Mägerle and Maurer, 2009; Kokkola et al., 2010; Kahn et al., 2014; CLS, 2017)

The period between 07:00 and 12:00 CET is dedicated for the funding or pay-ins process, where the initial pay-in schedule (IPIS) and revised pay-in schedule (RPIS) are posted at 00:00 CET and 06:30 CET correspondingly (Mustich, 2016). The participants are supposed to transfer only the net positions (pay-ins) or around 2-5% of the gross settled amounts to the CLS Bank's central bank accounts (or at the Nostro agents) by 10:00 CET and 12:00 CET for Asia-Pacific and other currencies correspondingly (Kobayashi et al., 2007; Mägerle and

Maurer, 2009). The CLS Bank-approved payments system is used for all pay-ins to ensure their intraday finality (Miller, 2002). The CLS guarantees simultaneous fund transfer between the parties' sub-accounts using the PvP mechanism. The CLS settlement parties transfer the expected final balances (pay-outs) from its central bank accounts to the receiving CLS's settlement member accounts through the process assuming the operating time of the corresponding RTGS systems or "before the close of each RTGS system" (Miller, 2002; Mustich, 2016). The CLS system accounts do not keep deposits overnight by applying pay-ins and pay-outs via accounts of the transaction parties and CLS in RTGS systems of central banks. As the direct participants do not usually have direct accounts with all relevant RTGS systems, they have Nostro agents which ensure their accesses to settle the instructions in CLS. The operational timeline of the CLS system is shown in Fig. 1.8. (Sweet et al., 2007; Mägerle and Maurer, 2009; Kokkola et al., 2010; Kahn et al., 2014)

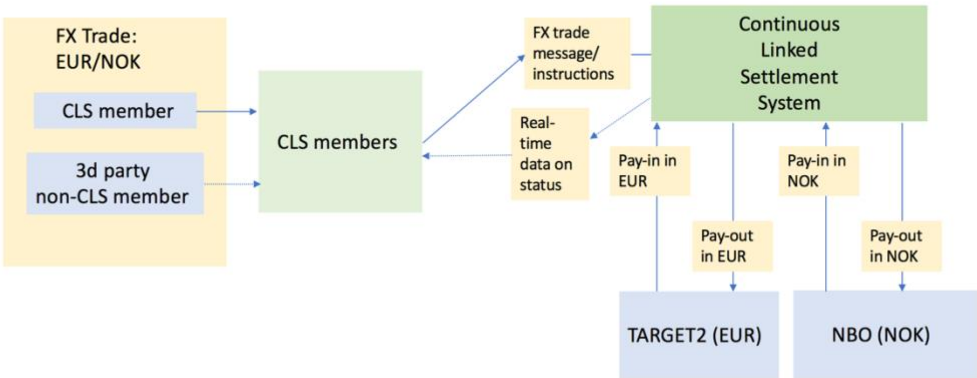


Figure 1.7: CLS settlement
Source: Author's own illustration created based on (Mustich, 2016)

The PvP settlement applied in the CLS system allows their settlement member minimizing the settlement risk in FX trades, as both legs of these deals are debiting and crediting the parties' sub-accounts simultaneously. Strong risk management procedures and liquidity management tools are applied to reduce the credit and liquidity risks for the settlement members. The credit risk is limited via three risk management tests in the CLS settlement process - keeping only positive overall balances across all subaccounts during the settlement cycle, limited aggregate negative position across members' subaccounts and limited negative position per subaccounts. The positive overall balances across all subaccounts are supported by a discount or a haircut in calculating the balances to protect against exchange rate volatility in relation to USD. The limits imposed on negative aggregate position across subaccounts and per account are defined by credit, liquidity, and operational characteristics of each member. The payments are held in the central bank accounts and settlement at the CLS bank, so the banker risk is minimized for the CLS and its members. (Miller, 2002; Mustich, 2016)

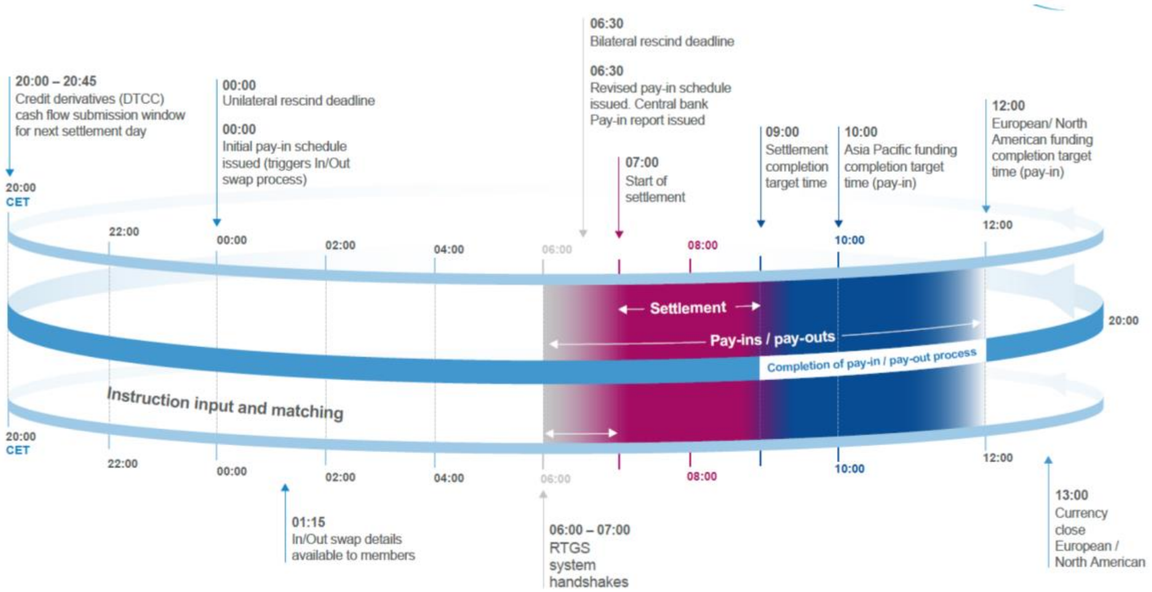


Figure 1.8: CLS settlement operational timeline
Source: CLS, 2015

The gross settlement of FX trades causes strict and large liquidity pressure on the settlement members during 5-hour settlement and funding cycle in the CLS system. The CLS system minimizes this liquidity risk by several ways - the pay-ins in the form of the expected final balances, spreading of the CLS payments over the settlement cycle, and inside/outside (I/O) swap between participants to reduce their pay-ins exposure. The required pay-ins can be arranged in tranches (usually 5 tranches) from the settlement members currency accounts to limit their liquidity pressure/shortage and avoid excessive liquidity in the individual subaccounts in the CLS. The I/O swap has an inside leg settled in the CLS Bank and an outside leg – through the traditional FX settlement arrangement, so two settlement participants can exchange their mutually offsetting balances in the FX instruments. However, the I/O swap increases the financial institution's exposure to the credit risk from the outside leg settlement, which needs to be settled though conventional correspondent banking arrangements and the RTGS systems on the same value date. Many central bank systems also support the settlement members with the necessary liquidity in the CLS settlement by offering interest-free intraday liquidity facilities or deposits against the lodging collateral in order to. (Kobayashi et al., 2007; Mägerle and Maurer, 2009)

The unmatched trades and their failure in the CLS system can expose the settlement participants to extra costs associated with an alternative arrangement. The CLS Bank ensure the refunds to its counterparty through the agreement with 2-3 liquidity providers per each eligible currency in the correspondent countries in case of some participants failure to make pay-in. In case of large currency exchange rate fluctuation (in excess of the haircuts) the settlement members can be assessed to the CLS loss allocation, and, therefore, to the credit loss. These rules mean that the CLS settlement members are exposed to the liquidity pressures as the refund payment can be in the unexpected currency, or the actual pay-ins can be bigger than expected or the actual pay-outs can be less than expected. (Kokkola et al., 2010; Kahn et al., 2014)

The conducting foreign transaction through the CLS system is pointed out by the reseachers as more expensive than through central bank money. The high cost of CLS settlement is associated with significant investments in technology and risk management applied in the CLS system. However, the application of the CLS Bank is increasing in FX trades, where 55% of the total FX obligations were settled by CLS in 2006 and about 68% in 2016 in the CLS-approved currencies.

1.4 Challenges in international payments

The current systems for international payments, card transactions, and CB are characterized by their participants and customers as inefficient, non-transparent, decentralized, cumbersome, disorganized, inconvenient, costly, and low access to it. It is associated with overall lack of transparency, complex and inefficient post-trade operations, expensive regulatory and compliance burden on the banks, liquidity management based on Nostro/Vostro accounts, screening procedures, and complex de-risking concept based on multiple intermediaries and a small number of available correspondents. (Mills et al., 2016; Brennan and Lunn, 2016; Sontheimer et al., 2017; Löber and Hauben, 2018)

The average cost for an international payment is about 25-35 USD or about 7,68-10% of the transferred amount (Denecker et al., 2016; McWaters, 2016; Brennan and Lunn, 2016). In accordance with the research of McKinsey & Company (2016), the main drives of the international payment costs are Nostro/Vostro liquidity (34%), claims and treasury operations (27%), foreign exchange costs (15%), compliance (13%), payment operations

(9%) and network management (2%). In case of cross-border payments the customers “pay a fee of 20-60 Euro on top of the prevailing foreign-exchange spread” (Denecker et al., 2016).

The most popular international retail payment products are business-to-customer or government-to-customer (B2C/G2C) payments and person-to-person (P2P) cross-border remittances. The value of the P2P cross-border remittances is estimated by about 530 billions USD in 2016, where substantial part is low value payments. The customers of these services pay from 7-8 % (PayPal, Western Union, TransferWise) to 10-11% (banks) of the transaction value as the costs for B2C/G2C and P2P payments. (Szmukler, 2017)

The compliance and fraud requirements induced with the Bank Secrecy Act in 1970 are named by the finance experts (Szmukler, 2017) as the biggest issue for banks and money transmitters today. These requirements introduced a compliance with the anti-money laundering/counter-terrorism financing (AML/CTF) & know your customer (KYC) & screening (sanction list) rules. In accordance with these rules the banks are obligated to establish the counterparties’ legal identity, report the transactions above certain level, and check who are their customers and their customers’ customers (Stark, 2017). New *compliance requirements impose huge cost and human-hours* on all banks. It was tightened in 2009 when the United States (US) Congress has been granted by the right to impose the fines on the non-compliant financial institutions where ‘suspicious activity’ has not been detected and prevented. In order to avoid costs and penalties, many international banks terminated and limited their relationships with small foreign banks. The highest explosion (about 70%) got the banks in Africa and the Caribbeans’ region (Taylor and Martinez, 2017). The global CB ties reduced by 25-39% and huge obstacles (payment delay, rise of fees, refusal) for charities, non-profit organizations, and remittance payments were created in new de-risking action. (Hopkins, 2017; Szmukler, 2017)

The second reason for inefficiency in international payments is *duplications and inconsistencies within the record-keeping or back-office system* of the participants. The manual reporting and payment reconciliation with double records and more than 10 account ledgers results in delays and additional costs (Brennan and Lunn, 2016). The studies demonstrate that 60% of B2B payments require manual efforts of 15-30 min (Park, 2006; Denecker et al., 2016). These efforts are related to back offices where variations in messaging, account structures, and unauthorized debits for counter-party payments need to be investigated and analyzed. For example, 17% of wire messages in FX trades need to be researched by business due to missing information related to different standards and regulations within the world. For small and medium-size banks all these challenges are added by tied-up liquidity in Nostro/Vostro accounts within large correspondent banks. The information asymmetry results in counterparty risk, and therefore, high costs, disputes between parties, and capital tied up. (Park, 2006; Löber et al., 2017; Szmukler, 2017)

The next reason is *uncertainty within complex international payment network*. The supporting of a global payment network is more expensive than in case of domestic payments, as the fulfilment of different standards and regulatory frameworks is needed. A cross-border payment takes about 1-5 days to be received by the beneficiary (Denecker et al., 2016). The security trading process takes about 2-3 days in the current set-up, which includes trade execution, trade clearance, and trade settlement (Biella and Zinetti, 2016). These delays are related to errors, high rejection rate, and other frictions within many parties of the international payment infrastructure. A lack of transparency within the network often creates an inability to determine the arrival time for a payment, transaction fee, and even payment tracking. It is complicated with the delays of the payment posting on a beneficiary's account. Such low visibility within international payment flow increases settlement and liquidity risks and limits the banks' ability in creating new services. Due to these reasons, many banks are cutting their less profitable locations around the world in order to limit the compliance costs and risks. (Szmukler, 2017)

The cross-border payment systems involve significant economies of scale that result in high concentration and monopolies. *Market and systematic imperfections* (settlement, liquidity, and systematic risks) are other significant problems which the CB participants face. The low competition and settlement based on the trust channels induce complex middleman process for small- and medium-size financial institutions. The complex structure of CB transactions with a lot of intermediaries causes additional costs related to the management of operational, financial and legal risks. As international payment industry possesses a significant network effect, the competition and innovations are limited, and therefore, overall efficiency is low. (Kokkola et al., 2010)

All the above described challenges of CB payments induced the *increase of nonbank offer* for cross-border payments. The companies like MoneyGram, Western Union, PayPal, TransferWise account for 40% of revenues in case of consumer-to-consumer (C2C) payments today. However, 95% revenue of B2C and B2B payments are still controlled by the banks. B2B segment is the most profitable and growing in international payments, as it generates almost 80% of its revenue. The fintech companies (SAP, Traxpay, Taulia, Western Union Business solution) have started to offer transparent cross-border solutions for B2B payments with integrated digital foreign/exchange, accounting and customer features. (Denecker et al., 2016; Manchiraju et al., 2016)

In order to compete with new offerings of fintech companies, the current set-up of CB fund transfer looks to complex and manual. The CB needs to have a transparent cost structure and standardized information, 24/7 operating cycle time, overhaul or less complex legal infrastructure & back-office efforts. The settlement and post-settlement processes need to be disrupted as the most cumbersome part of CB. These changes will allow controlling operational and settlement risks. (Manchiraju et al., 2016; Chapman et al., 2017)

1.5 Risks in settlement system of international payments

International payment value chain consists of communication network, intermediaries, access interfaces, settlement, clearing, and other complex infrastructure with agreed rules and rights (Kokkola et al., 2010). The Basel Committee on Banking Supervision identified several risks related to the settlement and clearing of FT transactions as core processes in the payment system and published them in its Global Supervisory Guidance (2013). These risks are market risk (replacement cost risk), principal risk (Herstatt risk), liquidity risk, operational risk and legal risk (CLS, 2017). The most of these risks are related to non-simultaneous finality in the central banks' payment systems due to different time zones in cross-border payments in multiple currencies and related to non-PvP settlement. The fundamental trust issues are especially crucial in international payments, so neutral intermediaries and centralized ledgers are applied widely to ensure the agreed transaction and its veracity. (Noël, 1993; Brennen and Lunn, 2016; Arjani, 2007)

Credit risk or principal risk is related to a case when a net debtor is unable to settle its obligation, and therefore, the counterparty becomes exposed to financial failure, insolvency or bankruptcy. In order to eliminate this risk, the settlement parties are forced to pledge a collateral in many settlement systems, like TARGET2 and CHAPS. In international payments and FX trades the credit risk is defined as a Herstatt risk (Tanai, 2008). The RTGS and the CLS systems are less exposed to the credit risk, as the transactions are settled simultaneously, and thereby, the parties' value and duration exposure is minimized. The central bank money is assumed safe, so the big financial institutions try to utilize them the most to limit the credit and system risk in their clearing and settlement (Kahn et al., 2014). However, these risks can be imported from other closely interconnected settlement systems where intraday finality can be delayed, such as foreign settlement systems and domestic systems with net settlement. Peak days in the global markets can impact crucially on the exposure to counterparties, and thereby, increases the credit risk (Table 1.4). (Impenna and Masi, 1997; Nielsen, 2005; Park, 2006; Sweet et al., 2007)

Table 1.4: Counterparties peak in gross settlement value in CLS in 2015
Source: CLS, 2017

	Average daily gross settlement, billion USD	Peak day gross settled in billion USD
Max exposure to counterparty	64.9	163.1
Average exposure to counterparty	1.7	7.1

The credit risk can result easily in *systematic risk* where one party's financial failure leads to the failure for the other party's payment, and thereby, to chain of defaults or domino effect. It is associated with unsecured and uncontrolled credits in the settlement systems and the parties' counting on incoming payments to cover their obligations (Folkerts-Landau et al., 1997). The systemic risk is especially critical for the netting system, where settlement of multilateral balances at the end of the day can failure due to one party's insolvency. The large value payment arrangements and big multinational banks expose the payment market participants to higher systemic risk, so confidence in the counterparties and overall payment infrastructure becomes crucial. In the CLS system the special schedule of the trades' settlement is applied to minimize the systemic risk. (Patrikis, 1995; Impenna and Masi, 1997; Park, 2006)

The cross-border payment legs in different currencies are not settled simultaneously due to the time differences or other specific operating conditions in the CB arrangements. These delays in the settlement of liability by the counterparty cause *liquidity risk*. Liquidity risk is associated with the inability of a financial entity to provide sufficient funds in time to enter into a transaction. The system limited aggregate liquidity combined with settlement delay can result in a special case of the liquidity risk (a gridlock case), when the system is unable to execute several transfers due to the failure of the previous transfers (Kahn et al., 2014). As the FX currencies are traded more actively in the recent years, the security of the large source of funds is necessary in all payment arrangements (CLS, 2017). The central banks apply open-market operations and offer intra-day loans through discount window to solve the liquidity problems in RTGS systems. It secures that the payment counterparties are not short of liquidity in the settlement process during the operating time. The combination of the liquidity and credit risks results in settlement risk in international payment systems. In FX transactions the CLS system is supposed to be out of the settlement risk thanks to the applied PvP mechanism, while the CB arrangements are exposed cruelly due to invisibility of the direct link between two legs of the same FX deal. (Patrikis, 1995; Impenna and Masi, 1997; Folkerts-Landau et al., 1997; Sweet et al., 2007)

The volatility in foreign exchange, interest rate and other prices results in *market risk* in the settlement system of the international payments. The market risk depends a lot on futurity or a time interval between the trade consummation and its final settlement in the payment system. The special form of this risk is incidental market risk, which is associated with the fluctuated value of collateral used to support the transaction. (Patrikis, 1995)

Operational risk is related to adequate redundancy of the system to different breaks, such as electricity cut, security failure, or other operational or technical force major. For example, the payment systems should have several levels of contingency arrangements to avoid its crash. The operating risk is minimized by special design of settlement, such as RTGS, and via contingency arrangements. For example, Danmarks Nationalbank covers its RTGS Kronos system through dual-center operations or support by two independent IT centers in case of technical break. The operation risk or technical failure is named as the main reason for the credit risk by Sweet et al. (2007) (Patrikis, 1995; Nielsen, 2002)

The chance of invalid and binding settlement of transactions is related to *legal risk*. Many payment instruments are lacking the specialized law to address the different issues happening in the international settlement systems. The multilateral and ultra vires transactions are especially prone to the legal risk. The huge record-keeping system of CB intermediaries can easily result in privacy and compliance issues (Patrikis, 1995; Biella and Zinetti, 2016; Chapman et al., 2017)

In accordance with Sweet et al. (2007), the average exposure for the CB settlement is 71 % of the total daily obligation in irrevocable period. The uncertain period increases the average exposure of the financial institution by 17 %. Although the CLS settlement is applied for around 60% of the FX trades in the world, settlement risk is still accounting for a considerable part of international trades even within CLS members. The trades involve non-CLS currencies, non-CLS members, or cannot be settled in the same day or certain next day CLS cycle are the main reasons of the significant settlement risk in the international trades. In accordance with Sweet et al. (2007) the trades with settlement risks accounted for 36% of the FX obligations in 2006.

In the current system the intermediaries (banks and financial market infrastructure) match the trade parties, and the central banks settle the trades legs, so they bear the above discussed risks. In order to handle and limit the risks the intermediaries require prefund or collateral, perform special control procedures and measure credit and liquidity risks per each counterparty in accordance with their risk profile. In order to mitigate the settlement risk in daily operations, the financial institutions apply pre-settlement and settlement risk limits, consider the appropriate settlement time and the CLS system for high-value FX deals. The central banks provide time-critical liquidity via day and overnight loans in the RTGS systems to avoid liquidity dry-up and system risks (Marshall, 2017). The collateral requirements on the account holders, delivery versus payments or payment versus payment mechanisms are other ways applied by the regulators in order to minimize the risks in the payment systems. However, in accordance with the surveys, the banks still tend to underestimate their settlement risk exposure, so the central authorities should monitor this risk, although it is impossible to identify it via periodic reporting and balance sheets of the financial institutions. (Harrison, 1997; Tanai, 2008; Lindley, 2008; Mills, 2016; CLS, 2017)

1.6 Distributed ledger technology

In accordance with the report of the World Economic Forum (2016) Distributed Ledger Technology system represents “a repository of information (or database) underpinning asset exchange between parties over one or more peer-to-peer network platforms” (McWaters, 2016). The DLT arrangement consists of stores, validators, and registers (Lacity and Ross, 2018). The scheme of a DLT-network is illustrated in Fig. 1.9. These decentralized systems are able to authenticate and validate digital data or transactions using encryption mechanisms, and peer-to-peer validation, and thereby, exchange of value. (Löber et al., 2017; Biella and Zinetti, 2016; Dalal, Yong and Lewis 2017).

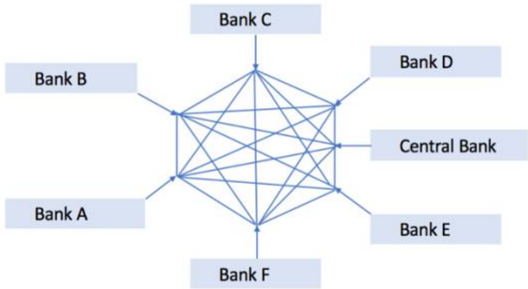


Figure 1.9: DLT network
Source: Author's own illustration created based on (Natarajan et al., 2017)

The applied token, agreed consensus mechanism, structure, network of nodes, rules and shared ledger are common features for DLT-based arrangements (Sontheimer, 2017). The nodes can be arranged over the internet or at a private network. The DLT arrangements can be implemented with different access to the network – restricted (permissioned) or unrestricted (permissionless). The access characteristic is crucial for establishing secure protocols, governance, and operational arrangements. In case of the permissioned network (e.g., Ripple) the new entity needs to get a permission to join the ledger or act in the ledger, while the open ledger (e.g., Bitcoin, Ethereum) is open to all. The restricted access provides higher information security and scalability that is beneficial for banking and overall financial industry. However, the unrestricted network can decrease "the tiering of relationships" in payment and settlement systems of financial institutions (Löber et al., 2017).

The nodes or parties of the DLT-based network can differentiate based on their functions or rights - a participant node, a notary node, and a supervisory node. (Löber et al., 2017) The up-to-date record information can be stored on each of these ledgers or they can have special access right to the common ledger. The ability to maintain tamper-resistant records allows the network to provide special access rights for different users, for example, reader access for supervisors and auditors. In case of notary network, the participants can store only their own data, while the notary and supervisory nodes keep all transactional records. In this case the supervisory node (or system administrator) is responsible for operating resilience and compliance monitoring, while the notary node (or validator/auditor) takes uniqueness function. The ability to get information immediately could allow reducing costs for regulatory compliance procedures. (Mills et al 2016; McCormack et al., 2017)

One of the most important aspects of DLT is validation and consensus mechanisms between the nodes/synchronized distributed ledgers. The protocol or governance arrangements based on complex algorithms define the set of rules based on which the parties can facilitate consensus about the current state of the ledger, whole historical records (entire ledger) or ledger updates (batched blocks or blockchain). The protocol defines how the parties agree on the new state of the ledger and synchronize it. It allows achieving a single version of truth, or "golden copy" of the ledger, for all nodes. (Tandulwadikar et al., 2016; Evans-Greenswood et al., 2016; Löber et al., 2017)

Validation procedure and security of transactions are based on cryptography tools (public and private keys) in the DLT arrangement. The cryptography tools allow participants to authenticate themselves and other approved parties, confirm record and support consensus on ledger update. The ledger update can be achieved only via cryptographic digital signature, or a private key, to restrict the access for unapproved parties to the information. The public key is used to identify the address of the receiving account. The applied consensus process guarantees an immutable state of the ledger or ledger integrity and security of the transactions against malicious threat. (Biella and Vittorio, 2016; Tandulwadikar et al., 2016)

The most attractive feature of DLT arrangement is an ability to implement smart contracts or codified conditions and terms for agreements' implementation, that facilitate, enforce or verify the performance of a contract (Evans-Greenswood et al. 2016). The self-execution applications or smart contracts could allow to enhance performance of certain parts in the payment arrangement. For example, clearing and settlement of transaction can be performed straight on the network which reduces records management and back office processes (Biella and Vittorio, 2016). The application of smart contracts can reduce contracts uncertainty, counterparty risk and automating the processes in trade finance, derivative trading, security settlement, supply chain management, and other complex business processes. The specific bilateral business needs with certain logic can be encoded and secured in the arrangements, that allows improving the efficiency or eliminate many operations of the back-offices. However, special attention should be devoted to security aspects and immunity to faulty code in case of the smart contracts' application. (Peeters and Panayi, 2016; Löber et al., 2017; McCormack et al., 2017)

DLT is viewed by many financial experts as a technology which allows disrupting payments, clearing, and settlement, as it is promising a lot of improvements over the current state of financial and trade systems. Firstly, DLT can allow removing intermediaries and proprietary infrastructure of third parties, as it contains a verified record of every transaction.

Disintermediation can reduce complexity, double-spending, fraud, and, thereby, the system achieves higher end-to-end processing speed. Secondly, full automation of complex business processes (e.g., payment, settlement, and record-keeping) bring higher transparency and immutability of data records, and therefore, it can reduce regulatory burden, duplication, reconciliation and storage expenses. Thirdly, decentralized public transaction records (distributed data management) and application of cryptography can allow enhancing security aspects and decreasing operational risks, and achieve higher resiliency and data integrity. Fifthly, real-time tracking and settlement of transactions can enhance availability of funds and reduce financial and operational risks. Sixthly, multiple synchronized ledgers allow strengthening reliability and resiliency of the system as it avoids “a single point of failure”. (Mills and Netmith, 2016; Tandulwadikar et al., 2016; Sontheimer et al., 2017)

Cryptocurrencies

One of the most popular types of DLT is cryptocurrencies based on blockchains (e.g., Bitcoin). The blockchain represents a peer-to-peer network, where transactions are validated through a consensus process and without any central authority (Biella and Zinetti, 2016). All parties are represented by their computers and are called nodes or miners. The cryptocurrencies present digital assets or accounting tools which enable transactions within the untrusted parties, as the shared log book of all transactions support the transaction without the third’s party validation (Chapman et al., 2017; Peck, 2017).

The mechanism of the well-known Bitcoin was introduced by a person or a group of persons with the pseudonym Satoshi Nakamoto in 2008. Blockchain is based on verification and adding transactions into a “block” and further to chain, which represents the history of transactions. Each transaction in blockchain contains a hash (unique signature), which combines a reference to the previous transaction and a digital signature of the initiated node. The miners validate the transaction based on the given hash and write batch of valid transactions through solving computationally complex algorithms. The cryptography is applied to provide a process of agreement between the nodes or participants of blockchain. The nodes should agree on a new state and update their copies of the ledgers by linking new block to the previous one for each new transaction. The confirmation process in Bitcoin network can take about 10 minutes, and its throughput of transactions is up to 7 records. These limitations are caused by the applied proof-of-work (PoW) consensus protocol, where the parties are competing to validate new transactions. It is named as a network latency and applied to achieve higher security in permissionless networks. Bitcoin is attributed by the experts to the first generation of tokens. (Biella and Vittorio, 2016; Dalal et al., 2017; Sontheimer et al., 2017; Löber et al., 2017; Peck, 2017)

The next two generations of tokens were named as new (public) blockchain systems (Ethereum, Peercoin) and dApps/other (Counterparty, Augur). New generations of tokens have added new features in cryptocurrency operational framework - new consensus mechanisms (ex, proof-of-sake or Byzantine fault-tolerant protocol, 'global consensus ledger' in Ripple), decentralized computation platforms with 'smart contracts' (Ethereum) and other features. The application of the consensus mechanism based on proof-of-sake or Byzantine fault-tolerant protocol allows validating the transactions in seconds and achieving high throughput of transactions (Biella and Vittorio, 2016). Ethereum platform enables trading of different assets based on predefined rules in smart contracts. (Chapman et al., 2017; Sontheimer et al., 2017)

1.7 Application of DLT for international payments

All wholesale payment systems process transactions between financial institutions using their digital records and based on relatively simple structures - several distributed ledgers with accounting solutions founded on centralized legacy. These facts mean that these critical payment arrangements are viable targets for DLT application (Peck, 2017; Chapman et al., 2017). In accordance with the analysis of Lacity, Moloney and Ross (2018), the international payment industry can reduce the transaction costs by 15-20 billion USD in the coming years by application of DLT systems.

One of the most obvious application of DLT is to simplify the processes associated with settlement, clearing, and reconciliation. As DLT network is decentralized, there are no needs to validate and support the transactions, and therefore, less needs for intermediaries, complexity, separate reporting processes, Vostro/Nostro accounts, and huge back-offices. It can lead to shorter confirmation time, faster automated settlement, less reconciliation and verification processes, less opaque services for end-users, higher reliability and traceability. As all transaction parties are fully informed in DLT network with up-to-date information, it reduces counterparty and custody risks and costs associated with information asymmetries, uncertain funds availability, Vostro/Nostro liquidity, dispute solving, manual processing errors, and other inefficiencies of the current international payment infrastructure. The complex liquidity management and strict legal requirements can be addressed better with the DLT platforms. The audit trail and reporting may be clearer and more consistent using common master database and less intermediation, that leads to greater financial inclusion. The settlement and clearing can be arranged to 24/7 and not limited to the operating hours of central banks. The trusted intermediaries can be represented by a shared database. (Biella and Vittorio, 2016; Evans-Greenswood et al. 2016; Brennan and Lunn, 2016; Dalal, Yong and Lewis 2017; Chapman et al., 2017; Szmukler, 2017; Lober and Hauben, 2018)

In the DLT-based arrangements the financial institutions can be able to manage a common shared and consistent state of records or a financial relationship. Financial market infrastructure can act as the trusted party, which tracks and records transactions in the centralized ledger. When one of the parties wishes to update own copy of ledger, the agreed consensus algorithm can be applied to synchronize it with one another. The security can be supported by cryptography via immutability or append-only characteristic of the set-up, which means an ability only to update the ledger (not delete or edit the previously agreed records). The regulator can be arranged as a supervisory node to monitor the trades in real-time and halt illegal transfers. The application of a notary node allows avoiding irrecoverability and irreversibility that is seen in Bitcoin network (Brennan and Lunn, 2016). The transactions and customer data can be immutable and more transparent, so it supports the financial parties in their compliance efforts and risk measures. The synchronized ledger can provide information for KYC&AML&CFT checks, screening, tax and audit checks. The application of smart contracts and digital obligation can alleviate operational errors. (Evans-Greenswood et al. 2016; Stark, 2017; Chapman et al., 2017; Nordrum, 2017)

The permissioned DLT arrangement is the most obvious choice for critical international wholesale payment system, as it is used to be based on trusted parties and is flexible in case of errors. The closed settlement system can support irreversibility or finality of the transactions, and alleviate drawbacks of open DLT networks, such as low throughput and storage capacity, energy consumption, latency, poor privacy, financing of terrorism, and money laundering. Higher immutability of transactional data against errors and cyber-attacks, and lower visibility of transactional data are other benefits of the closed DLT platform. The permissioned type of DLT allows avoiding privacy breaching and secret business data, and therefore, be compliant with the banking law. The absence of energy and time expensive PoW type activity allow running the permissioned DLT cheaper compared to an open DLT network. However, a bigger and untrusted network would allow keeping more data and distribution, and thereby, be more resilient. (Biella and Vittorio, 2016; Mills et al., 2016; Peck, 2017; Nordrum, 2017; McCormack et al., 2017; Chapman et al., 2017; Lober and Hauben, 2018; Lacity, Moloney and Ross 2018)

The possible scheme for the global payments is illustrated in Fig.1.11. The first step is presented by the processes in the sender banks – regulatory compliance checks and screening (1) and collection of the transfer funds. The transfer tracking will be not needed as smart contract can support all the obligations for the fund transfer (2, 3). (McWaters et al., 2016)

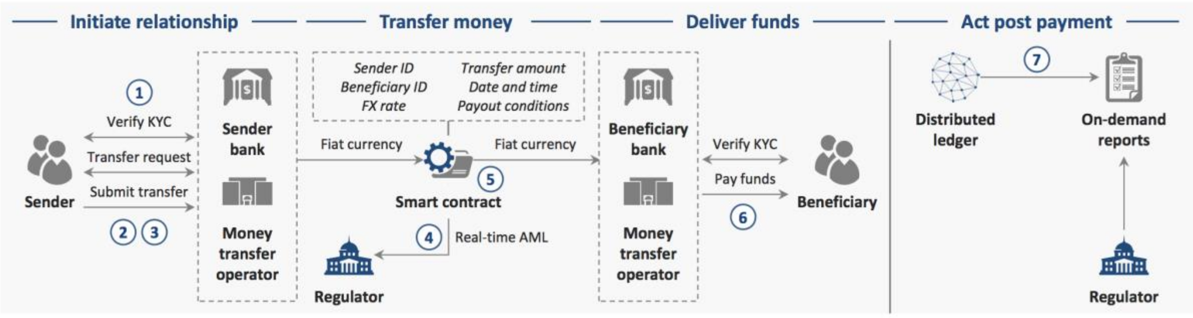


Figure 1.11: Inter-banks payment system based on DLT
Source: McWaters et al., 2016

As the next step, the fund transfer can be performed based on the smart contract with the regulator's monitoring (4-5). In this process the smart contracts will enable guaranteed delivery of the fund transfer. As the correspondent banks will not be needed, the fund transfer requires less costs and fees. At the final step (6) the beneficiary bank or money transfer operator provides the regulatory compliance checks and pay the transfer funds. The regulatory compliance process can be simplified or automated through the storage of all digital profiles on the DLT network. The regulator is able to monitor and continuously review all the transaction history on the ledger (7). (McWaters et al., 2016)

Basically, the DLT infrastructure can contain three layers. The control layer is responsible for monitoring read and write accesses. The instruction propagation and transactions validity are controlled in communication, consensus, and content layer. The contract layer is implemented through smart contracts where transactions are self-executed based on certain criteria. Each node bears the costs associated with computing infrastructures, digital network connection, and maintaining a local copy of the shared ledger. New payment system can be based on tokens of stored value or digital form of central bank money, be presented as general purpose or limited to wholesale. It can reinforce the payment and settlement resiliency for the wholesale payments. New settlement instrument can reduce operational costs and provide higher efficiency in terms of availability, liquidity, collateral use, and risk management. (Brennan and Lunn, 2016; Lober and Hauben, 2018)

Many international companies have already started the projects to uncover the opportunities of the DLT technology for international payments. The San Francisco-based company Ripple is targeting to integrate its open-source and consensus based DLT network with legal institutions to improve international payments between financial institutions. The settlement solution ‘xCurrent’ enables payments through Ripple Medium using native cryptocurrency XRP or through corresponding accounts (Schwartz, 2018). The decentralized database Corda allows parallel transactions using data sharing and notary which signs based on consumed inputs (Hearn, 2016). The bank-owned consortium R3 and Corda presented a proof-of-concept for shared KYC register to manage customer information (Szmukler, 2017).

1.8 Critics against DLT and its challenges for international payment application

Several features of DLT need to be considered before its application for international payments. The first of them is technical and operational setup, such as connectivity between the parties, a way to handle the doublespending problem. The Bitcoin utilizes the PoW concept where miners spend huge computational power to propose a new block. The Ripple applies protocol consensus algorithm or special procedure to deliberate, agree, and validate the ledger. The most of DLT networks apply majority-rule for the consensus and, thereby, believe in honesty of majority of the participants (Schwartz, 2018). The settlement finality is named by many authors as the main pitfall in the blockchain system. As the PoW mechanism is probabilistic, it results in a small chance that the transaction can be reversed. However, the notary concept allows avoiding this problem, as its consensus mechanism is based on the approval be a notary node, and therefore, it is deterministic and fast. (Chapman et al., 2017)

The second challenge is the regulator role over the critical system. Although DLT-based arrangements can reduce operational and financial inefficiencies, coordination or centralization of the arrangement by a trusted supervision is crucial. The central banks should act with oversight role to foster, monitor, and assess in order to ensure safety and efficiency of the new arrangement. However, this setup shifts the load of AML/KYC/CFT checks, screening, tax and privacy checks from commercial banks to central banks (Lober and Hauben, 2018).

The third challenge is low immaturity of DLT for a wide commercial application due to its security, privacy, and operational issues. In the distributed arrangements the customer and transactional data is shared among several ledgers, so it has greater exposure to malicious actors. The financial institutions are responsible to control and protect customer data in the payment systems, especially in the cross-border lines. Many DLT network demonstrates privacy uncertainty associated with new European General Data Protection Regulation (GDPR) came into effect in 2008. The public blockchains (Bitcoin, Ethereum) are the main targets for this regulation, as the information about EU citizens are shared transparently and difficult to erase ("right to be forgotten") in these set-ups. However, new confidentiality-protecting and privacy techniques allow avoiding these problems by protecting the participant's identity via hiding the public key (ring signature, stealth address) or hiding the transaction data (enigma protocol). (Stark, 2017)

The operational risk is another most names risk of DLT network. Although several proof-of-concepts (Jasper project, Ubin project etc) have been introduced, neither of them was production-level system, and thereby, they could not demonstrate the necessary resiliency, scalability and security. Many technology experts are pointing out that the existing financial and payment infrastructure can be incompatible and inoperable with DLT due to old technologies within financial institutions (Sontheimer et al., 2017; Löber et al., 2017). It can result in slower processing of the transactions compared to traditional databases. The scalability is limited by the data flow limitation in the particular network. The first phase of the Project Jasper demonstrated that the public internet allows up to 14 transactions per sec in the platforms based on the PoW (Ethereum). The notary system does not have constraint in the scalability, as the consensus is based on the verification by the party and notary nodes (Stark, 2017). However, the information sharing through a public Internet connection may limit the transaction volume, so scalability, operational resilience, and timeliness issues need to be considered before application of DLT in international payment systems (Denecker 2016).

The next challenge is related to the absence of legal aspects and government framework for DLT implementation over the world. The absence of technical interoperability standards and reference architecture is a big risk for DLT's wide application in the conservative field of cross-border payments (Peck, 2017; Sontheimer et al., 2017; Löber et al., 2017). As the international payments industry is characterized by significant network effect and economies of scale, only international joining efforts of settlement institutions, central banks, regulators, banks, and other stakeholders can help to achieve more efficient payment infrastructure. The creation of solid legal frameworks, data and information standards, interoperability protocols, compatible processes, collective platforms, regulation frameworks, standard-based Application Programming Interfaces (APIs) and proved architecture concepts will lead to the widespread adoption of DLT in the payment industry. (Mills et al., 2016; Szmukler, 2017; Chapman et al., 2017; Dalal, Yong and Lewis 2017; Lacity, Moloney and Ross, 2018; Lober and Hauben, 2018)

1.9 Literature review

Only several researchers have analyzed settlement risk empirically in the payment systems. It is associated with high complexity of the payment systems themselves, especially international one, and a lack of necessary data. However, there are many papers where different factors influencing the international settlement process are investigated.

Northcott (2002) has investigated settlement risk in the form of contagion through interlinkages between financial institutions in the payment system of Canada. The contagion is defined as a case when the transaction counterparty's net position drops below its capital, so this counterparty defaults on the obligation payment. The model of the DNS system based on the bilateral positions of 12 direct dealers was used in order to estimate the participants' exposures and risk of contagion in the Automated Clearing Settlement System (ACSS). The cases of normal and extreme conditions demonstrated, that the ACSS has limited risk of the contagion in the designed environment.

Mills and Nesmith (2007) presented several stylized facts concerning the timing of intraday settlement in the payment and security settlement systems. The authors applied the cost of intraday liquidity, the overall design of the system, and the extent of settlement risks as factors influencing the timing for the settlement of transactions. The paper demonstrates that the funds settlement was concentrated usually later in the day. The intraday overdraft fee introduced in 1994 did not influence significantly the timing of Fedwire funds settlement in the payment system. However, the overdraft fee influenced the security settlement. The data demonstrates that the settlement became concentrated early in the day, and the amount of overdraft reduced significantly with the introduction of the overdraft fee to Fedwire funds for the settlement of securities. The further increase of the overdraft fee did not show significant impact on the settlement timing in payment and security settlement systems.

Tanai (2008) investigated the FX settlement risk in the Hungarian banking system using the data from the personal interviews at 13 banks and the questionnaires received from 14 banks covering 95% of the FX market in Hungry. The duration of FX settlement risk exposure was calculated using the substitution scheme for cancellation deadline, so only the RTGS systems' deadlines were taken into account. The deadlines for the providing the transaction instructions in the correspondents or Nostro banks have not been considered, as these deadlines were missing in the contracts and can be assumed as insignificant in accordance with the provided interviews with the Hungarian banks. Tanai concludes that the main factors influencing the duration of the settlement risk are a time difference between the operating times of the applied settlement systems. The CB is the most preferable method for FX settlement in the Hungarian banks, and therefore, 75% of the settlement risk is concentrated among five banks and far exceeding their Tier 1 capital in accordance with the paper's results. The interview demonstrated that the settlement risk exposure duration lasts up to one day or within value date, hence, many banks do not want to apply the CLS arrangement to settle FX trades in order to eliminate their settlement risk. Tanai is surprised with lack of documentation stating the CB relationships and allowing to identify the deadlines and other relevant information related to the settlement.

Allsopp et al. (2009) have investigated the RTGS systems in difference countries in order to assess their compliance with the CPSS core principles for "systematically important" payment systems. The surveys were sent to 98 central banks running the RTGS systems to provide the research. The authors found out that the eligibility or requirement for RTGS system access varies in different countries and this fact precludes the financial institutions to provide their services to customers at the most effective way. At the same time the retail systems have ultimate access to the central bank settlement without the recognized safety concerns. Allsopp at al. found out that credit provided by the central banks against collateral put up is the main source of intra-day and overnight liquidity needs of the participants in all RTGS systems. Although the pricing in the RTGS systems has low transparency, the authors' analysis shows that most of the central banks are targeting to recover only up to investment and operating costs through their RTGS systems' services. The transactions fee is the main sources of the revenue in most central banks' settlement systems. The RTGS systems with low transactions volume apply also fixed monthly or annual fees.

CLS Group (2017) presented an analysis of FX market and its importance in China. The authors show that the peak to average ratio of largest exposures is two times higher for renminbi compare with the same value of USD and EUR. It demonstrates that the CLS settlement of renminbi can allow the financial institutions to reduce their peak exposures in the peak days. The results listed Table 1.5 demonstrates also that the financial institutions are able to accommodate significant exposures and its variation in bilateral FX trades.

Table 1.5: Bilateral gross settlement exposures between CLS members for renminbi and CLS settled currencies in Q2 2015

Source: CLS, 2017

currency	average/largest exposure on an average day in billion USD	average/largest exposure on a peak day in billion USD	peak to average ratio of average/largest exposures
CNH, not settled in the CLS	0.05/0.76	0.17/5.62	3.77/**7.39**
USD, settled in the CLS	0.71/28.61	2.33/73.00	3.30/3.18
EUR, settled in the CLS	0.32/14.71	1.48/32.82	4.65/3.52

The analysis of the trading performance in the currency pairs EUR/CHF and USD/CHN in the periods of the increased market volatility demonstrated that the locked/crossed market happened only during 196 seconds in EUR/CHF trades based on the CLS settlement and during 7928 seconds in USD/CHN based on the correspondent banking' settlement. The locked/crossed market occurs when FX trade cannot happen, as the trade counterparty with the best bid price exceeds bilateral credit limit with the counterparty with the best offer price. It means that the CLS settlement is efficient and especially beneficial for the financial institutions in the volatile markets.

Pordis (2018) has investigated which instruments are exposed the most to the settlement risk. The author has applied financial mathematical methods to pursue the analysis of the settlement risk in stocks, derivatives, and foreign exchange. Pordis has used Ito's Lemma, arbitrage technique and probabilistic methods. The author concludes that the average exposure time is from 1 second to 4 days for FX spot contracts and 1-5 minutes for FX forward contracts. However, the analysis of FX spot contract was limited due to missing of the timestamp in a half of the analyzed trades. The applied probabilistic methods demonstrated that the probability of the currency cross exchange rate decrease during the settlement time of FX forward contract is more than 25%.

There are several current whitepaper and research papers, where the authors presented the DLT platforms and investigated their performance for further application in international and domestic payment and security settlement systems. The application of DLT in securities safekeeping and settlement was studied in the paper of Symons et al. (2016). The authors point out that DLT can allow reducing settlement latency in security custody model via less data alignment and reconciliation efforts. In the current set-up of cross-border transfers the accounts are siloed between different custodians or financial institutions, which leads to slow and inefficient settlement and reconciliation. Symons et al. specifies that the transactional data can be recorded in the synchronized database with easy access for all ledgers, so many intermediaries can be obsolete in the new set-up at least in a long term. However, the authors conclude that the life cycles of securities cannot be totally automated due to investors behavior aspects (unpredictability, unfair) and different corporate actions.

Tarasiuk (2018) investigated the benefits of securities settlement platform Target to Securities (T2S) migrated to full operation in 2017. The author has analyzed the official documentation of the T2S on the ECB official website and made an interview in INTERBOLSA to clarify the details, risks, and benefits of the new settlement solution. The settlement costs analysis of the T2S was implemented using the Giovannini model, and it demonstrated that the settlement fee dropped by 60% in the T2S platform compared with the set-up based on CSDs. Tarasiuk concluded that the T2S allowed reducing significantly the costs associated with the back-office functions and collateral.

In 2016 the project Ubin was initiated by Singapore’s central bank and financial regulatory authority (MAS), R3 consortium and several large international banks. (Dalal, Yong and Lewis 2017) It presents a digital cash-on-ledger project where Singapore dollar has a tokenized form on a DL. The first stage with domestic payments was executed successfully and demonstrated that continuous depositary receipt model (exchange cash collateral for Depositary Receipt on the distributed ledger) is working.

Starlander (2017) has analyzed the counterparty credit risk on the blockchain using the replacement cost and the potential failure exposure approaches. The simulation Monte-Carlo approach and interviews were applied to assess the blockchain in order to limit the credit risk. The author's analysis demonstrates that the smart contracts are seen as the main tool to limit the credit risk exposure for the participants in the blockchain. Starlander concludes that it is difficult to provide any solid results in accordance with the thesis topic, as the blockchain industry is new, and therefore, it is still lacking the overall framework.

The results of the Jasper Project done in collaboration of the Bank of Canada, Payments Canada, R3 and several commercial banks were analyzed in the paper of Chapman et al. (2017). The Jasper project was targeting to create "a proof of concept of a DLT-based wholesale payment system" of Canada or the Large Value Transfer System (Chapman et al., 2017). The project consisted in two phases, where the ability of assets' exchange between participants was demonstrated at the first phase and the ability of the platform to coordinate the transactions and diminish the liquidity needs was targeting at the second phase. The digital depository receipt (DDR) or digital representation of currency was created in order to transfer value or settle interbank payments. The DDRs have represented deposits with the Bank of Canada, where one unit of cash was pledged for one DDR. This system allowed no impact on money circulation. The settlement system was implemented in form of RTGS with possibility for the banks to enter the payments into queue (deferred settlement) or for immediate settlement. Chapman et al. concluded based on the project results that the current version of the DLT system cannot advantage over the centralized system used for interbank payments in Canada, especially in case of critical market infrastructure. However, the authors believe that the cross-border transactions can be improved through "interaction with a larger DLT ecosystem of financial market infrastructures" (Chapman et al., 2017).

Loben and Houben (2018) analyzed the possible implications of Central Bank Digital Currency (CBDC) on monetary policy implementation, payment system and financial stability. The wholesale variants with the access to predefined group and general-purpose cryptocurrency were investigated by the authors. In accordance with their conclusions the solutions of retail payment systems based on CBDC can't bring special improvements to the current infrastructure, as the current solution is "convenient, efficient and reliable, and has earned public trust and confidence over time" (Loben and Houben, 2018). Higher resiliency of the new payment instrument is not obvious based on the autors' view, as new currency would not be immune to network disruptions and other disasters. Loben and Houben suppose that new currency would attract higher demand from private sectors that may result in a loss of low-cost funding (deposits) for banks, shrink of their balance sheets, and consequently larger central bank balance sheet, especially in systematic financial stress. The general-purpose cryptocurrency can cause changes in commercial banks' business models, distortions in collateral, foreign exchange and higher quality assets' markets, and overall financial stability' risks. The wholesale cryptocurrency can disrupt financial markets, and creates additional load on central banks, but at the same time it can significantly improve efficiency of transactions, settlement, and clearing and provide higher financial inclusion and transparency. However, it is crucial to consider the requirements for AML/CFT, tax, supervisory and degree of privacy requirements to avoid reputational risks. In accordance with Loben and Houben the issuance of CBDC can't have a great impact on the monetary policy of the Central Banks, except cases of destress and crisis where the demand for CBDC may rise considerably without special rules for CBDC (e.g., negative interest rate). The demand for CBDC can be regulated through a set interest rate for CBDC that will discourage or encourage the demand.

Schwartz (2018) analyzed the Ripple network mechanism. The Ripple network applies a configuration model, so ledgers mark transactions and change accounts after reached consensus on the appended transactions. The accounts of the network are based on base58 encoded addresses (similar to IP addresses), outstanding balances, activation information and sequence number to track the transactions. The network includes validator or tracker nodes to perform the consensus process which is based on the majority-rule and altruism between participants. This set-up based on permissioned advantage of validator nodes and trust in them is criticized by community due to lower level of safety and overall contradiction to the decentralization concept (Schwartz, 2018). The majority-rule does not guarantee security for individual honest participants. The next criticized feature by the author is "nothing at stake" problem, where nodes can push faulty records into the system without any restriction. The next risk of the Ripple network is a difficulty to assign a trustful partner to run a validating node. However, financial institutions can be resistant to take such role in case of permissioned system due to possible ensued legal recourse related to KYC/AML requirements.

The outcomes of the Stella project conducted by the European Central Bank and the Bank of Japan in their joint paper (ECB and BJ, 2018). The Stella Project was dedicated to assessing the ways to achieve a Delivery-versus-Payment (DvP) in a DLT environment. The project concentrated on the implementation of cross-ledger mechanism ("cross-chain atomic swaps") to facilitate DvP in single-ledger and non-connected ledgers approaches. The digital signatures and combination of cryptographic hash and timelock functions ("Hashed

Timelock Contracts (HTLC)”) were utilized to transfer assets across two separate ledgers without intermediary. The authors conclude that the participants are exposed only to replacement cost and liquidity risk in the single-ledger DvP arrangement in case of the failed settlement as the asset and cash legs are exchanged at the end step of the settlement. In case of cross-ledger settlement with HTLC the participants of the trade are exposed also to principal risk due to asymmetry of the locking time for two legs in the settlement process. The prototypes for conditional linked settlement of securities and cash legs were implemented using Corda, Elements and Hyperledger Fabric platforms. The comparison of these settlement approaches demonstrated that the single-ledger DvP arrangement allow achieving lower liquidity risk, faster settlement and less privacy issues, but high volumes of transaction can create congestion and low network availability. The cross-ledger settlement with HTLC can operate with ledgers without any operational and institutional connections.

All these above papers demonstrate that the research community and authorities are interested in optimizing and improvement of international payment settlement arrangements. The DLT can be a good tool to do it. In my thesis I am going to contribute to analysis of DLT for application in wholesale international payments.

1.10 Goals and delimitations

The cross-border transactions volume increases by 3-4 percents every year thanks to globalization and changes in customer behavior towards more online services. It creates additional pressure on international payment arrangements and FX trades. Currently the trade execution takes a few seconds, while the post-trade clearing and settlement require hours or days to be completed. The long and uncertain settlement process creates considerable credit, liquidity, settlement, and other risks for the counterparties. This thesis presents an analysis of the settlement risk associated with traditional and new settlement arrangements of the cross-border transactions.

In particular, my thesis concentrates on assessment of three settlement approaches. The first traditional settlement arrangement is based on CB network. The CLS-based approach presents the second traditional settlement scheme under analysis in this thesis. The third scheme is a settlement of FX transaction via a DLT-based arrangement using USC. The first and second concepts are applied daily by the financial institutions in order to settle and clear their simple cross-border payments and FX trades. The settlement arrangements based on the DLT are new and still under development by the central banks, financial institutions, and financial system intermediaries. Although there are multiple DLT platforms in the market, there are no production implementations for the settlement of the wholesale payments yet. The USC project is chosen to investigate the settlement risk in this thesis, as the basic idea of this project is the most relevant for the wholesale cross-border payments. This project is backed by several big banks, and it has received a positive feedback from the research and expert community in accordance with the news (Dalay et al., 2017; De Meijer, 2017).

The main study objects of this thesis are settlement arrangements of simple cross-border high-value international payment and FX spot trade between Finland and the US. The settlement of the most popular currency pair EUR/USD is the main subject of my investigation, as this currency pair is accounted for a significant share of the world FX trade.

The simple settlement risk duration and exposure approach presented in the paper of Tanai (2008) is used to assess the settlement risk in each settlement schemes. The technical details of the settlement processes are collected through the websites of the CLS, the TARGET2, the Fedwire systems, several banks, and through several research papers. As the USC project is still in the development phase, and there are no technical details and prototype’s reviews (by the date of writing this thesis in the end of 2018), the settlement process scheme is guessed based on the white papers of the other DLT settlement systems and several research studies.

Although many researchers have investigated settlement risk in the payment systems of different countries, I was not able to find the extended overview and detailed computational comparative analysis of traditional and new cross-border transaction settlement systems. This thesis is devoted to this topic, as the wholesale payment system is still one of the most inefficient international systems which supports our well-being.

1.11 Structure of the thesis

The thesis is organized in the following way. Chapter 1 presents the extended literature review where the basis of cross-border payment settlement is described in detail. A special attention is paid to the current limitations and risks associated with traditional cross-border transaction settlement. This chapter gives also an overview of the DLT network concept, and it is finalized by a review of several research papers and investigations related to the chosen topic.

The applied methodology and data to assess the settlement risk in cross-border payment arrangements is described in Chapter 2. This chapter lists the chosen traditional settlement schemes and analysis assumptions for a simple cross-border payment and an FX spot trade. The scheme for the DLT-based settlement using USC is guessed based on the white papers and research overviews of the DLT concepts due to the limited information published about the USC Project.

Chapter 3 presents an analysis of settlement risk in the outlined settlement schemes and estimated results. A special attention is devoted to the settlement risk duration and exposure as the main analysis approach to assess and compare the settlement arrangements based on the CB network, the CLS system, and the DLT-based system using USC. Finally, Chapter 4 draws a number of conclusions based on the above analysis and calculation.

2. Methodology and data

2.1 Settlement risk

Settlement risk can be described as a combination of credit, liquidity, and replacement cost risks. In FX trades the settlement risk means that the financial institution is exposed to a probability that the short leg of transaction may not be completed at the same time when its long side is delivered in the clearing and settlement arrangements. The liquidity problems and default risk of the trade counterparties or their correspondents are the main reasons of the settlement risk. The settlement risk was named as the most significant risk in the payments before the introduction of CLS in 2002. It resulted in many delayed or failed (partial or total) payments. (Tanai, 2008)

The settlement risk of the particular transaction or FX trade can be measured by its duration and exposure. The exposure of the settlement risk is often significant and rapidly changing due to several settlement steps and its different risk profiles. The duration of the settlement risk is quite short and accounts for several hours or around one day. (Sweet et al., 2008)

Settlement exposure

The nominal value of outstanding transaction and currencies exchange rate fluctuation during the settlement process define the settlement risk exposure and value at risk for the transaction. The market value and replacement cost approaches (Eq.1) applied widely in the insurance industry can be used in order to calculate the settlement exposure of cross-border transaction and FX spot trade.

$$TE = MV^{e} + RC, \tag{1}$$

where TE is the total exposure of transaction or trade, RC is the replacement costs of the transaction or trade, and MV^{e} is the expected market value during the contract lifetime (Kozyr, 2016). The expected market value is defined by the nominal value of the simple cross-border trade and fluctuation of the applied currencies. In case of FX spot trade, the nominal of the purchased currency and currencies exchange rate presents the expected market value for each counterparty during the contract lifetime. The replacement cost of the simple cross-border transaction and the FX spot trade includes service fee to initiate new payment (trade) and penalties associated with the failed or delayed main payment in case of payment systems operational problems, or service provider (or counterparty) default or temporarily illiquidity.

The netting applied in the RTGS or the CLS systems reduces the settlement risk exposure from the gross amount of the transactions to the gross amount of the receivables. Tanai (2008) suggested applying the following equations to define the FX settlement risk exposure:

$$TE = \Delta SO - NE - \Delta SO_{\mathrm{CLS}}, \tag{2}$$

$$NE = \Delta SO_{\mathrm{netting}} - SO, \tag{3}$$

where ΔSO is the gross FX settlement obligation receivable, NE is the netting effect, ΔSO_{CLS} are the gross FX settlement obligation receivables settled via the CLS or PvP method correspondingly. The netting effect is used to deduct the gross FX obligations receivable resulting from transactions to be bilaterally and multilaterally netted ($\Delta SO_{\mathrm{netting}}$) without FX obligations receivable to be settled after netting (SO). (Tanai, 2008)

The PvP settlement applied in the CLS systems allows elimination of the principal risk, but the transaction parties are still exposed to the liquidity and replacement cost risks. The replacement cost risk is coming from the fluctuations in the currencies exchange rates until the confirmed and reconciled settlement (CLS, 2017).

Settlement duration

The definition of the settlement finality underlines the core of the settlement risk duration. The settlement finality denotes a moment when it becomes “irrevocable and unconditional” for the discharged obligation or makes entries in the accounts in a technical sense (Kokkola et al., 2010). The participants are subjected to the credit and liquidity risks in the time period between the instructions are submitted and the payment is settled with the finality. The payment finality was supported by the legislation by the Settlement Finality Directive in 1998 in the EU. It stipulated that payment orders and netting are enforced and bided legally on third parties. The netting rule needs to be taken with a precaution as it can cause a huge system risk in cases of one participant failure. However, multilateral netting allows reducing the credit and liquidity exposure, and thereby, brings less costs and higher efficiency. The enforceability of proper collateral should be accepted to protect against the credit risk exposure in case of insolvency legislation applicable to an insolvent party. The next important aspect is zero-hour rule which is applied to render void all the payments by the participants on their bankruptcy day. The Financial Collateral Directive of the EU precludes the zero-hour rule. The systems with the net settlement and optimization procedures need to take it into account.

The duration of the transaction exposure to the settlement risk depends on the country, currency, financial institution and other trade details. The average duration is up to 3 days or from (V-1) to (V+1). The longest exposure duration is related to the cases where the transaction counterparties are in the regions with significant time differences in their RTGS systems, like the US and Japan. The longest exposure durations are 47 hours for buying USD against KRW and 41 hours for buying USD against SGD. In this thesis I am concentrating on the transaction and trade between Finland and the USA, so the exposure duration of EUR and Nordic currencies against USD is listed in Table 2.1

Table 2.1: Exposure duration for Nordic currencies
Source: Sweet et al., 2007

	Buying $		Selling $	
	I, hours	IU, hours	I, hours	IU, hours
DKK	28	36	8	26
NOK	27	35	8	26
EUR	6-22	14-31	0-9	0-25
SEK	28	36	9	26

In accordance with Tanai (2008) and Sweet et al. (2007), the actual settlement risk duration of the transaction exposure is defined by two time periods. First one is between the point when the transaction instructions were sent, and the transaction becomes irreversible (or no longer can be cancelled unilaterally). And the second is between the point when the receipt is identified and the Nostro account reconciliation is done (currency received with finality). For example, in the FX trades the full value of the bought currency is exposed to the settlement risk during irrevocable and uncertain (IU) periods in accordance with the BIS report (Sweet et al., 2007). The uncertain period is actual for the financial institutions which check the trades outcomes with delays or provide the trades using their correspondents or Nostro agents, so they become aware of the trade outcome later than the receipts are due. Tanai (2008) distinguishes also the reference settlement risk duration of the transaction exposure by assuming only the official closing and opening time of the RTGS systems where the currencies are sold and purchased.

In this thesis the settlement risk duration is defined as a combination of settlement delays at the settlement sub-processes. In order to define the settlement sub-processes, the settlement schemes are defined for the simple cross-border transaction and FX spot trade via the CB network, the CLS system and the DLT-based system. These six schemes are described and illustrated in Chapter 2.2.

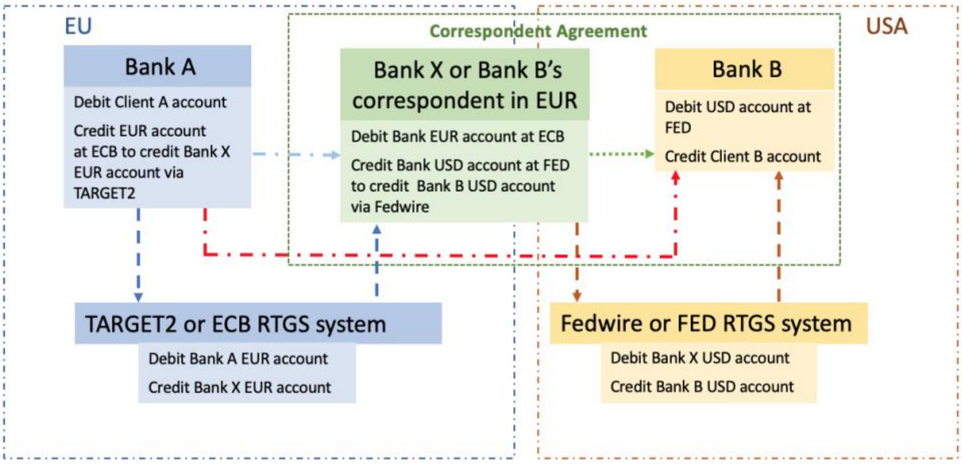
2.2 Traditional settlement arrangements under analysis

The financial institutions have a choice in a way to settle their payments and FX trades, as there are several solutions available in the market. In this thesis three settlement solutions are investigated in order to assess the settlement risk duration for a simple cross-border transaction and an EUR/USD spot trade between customer A in Finland and customer B in the USA. The notional values of the simple cross-border trade and FX spot trade are EUR 500 000 000, as the transactions are attributed to high-value payments. We assume that the Banks A and Bank B do not have a direct relationship in the traditional set-ups, and therefore, the Bank A needs to send the payment instructions of their Client A via several intermediaries or correspondent banks to the Bank B where the Client B has the account. The Clients A and B are big corporations or very small financial institutions which do not have settlement accounts at the local central banks.

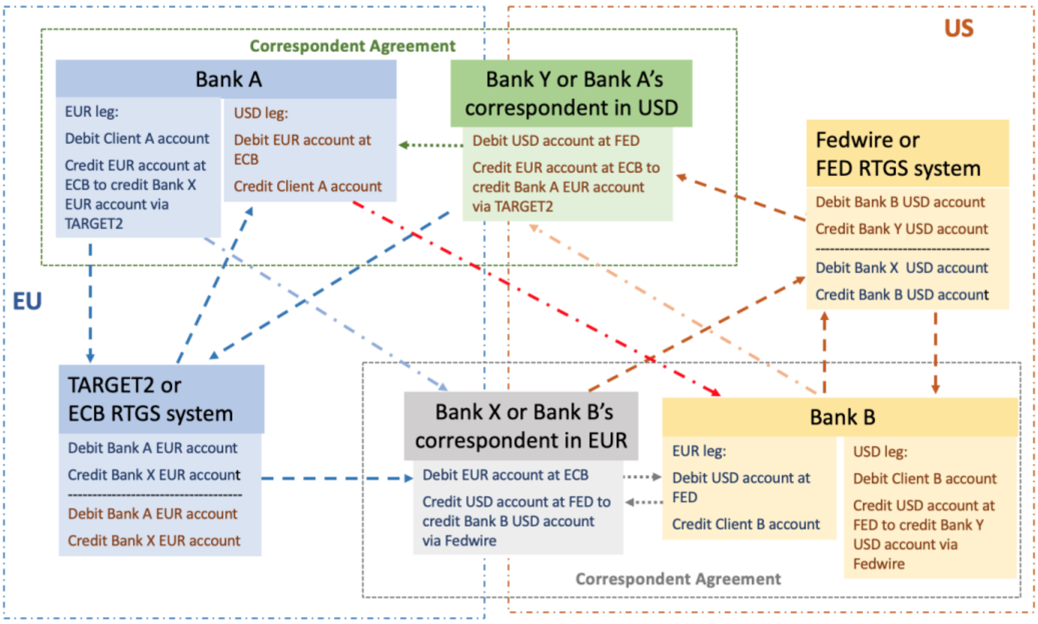
The required settlement day of the simple cross-border payment is assumed as T+0 or the same day. In case of the EUR/USD spot trade the required settlement day is T+2 or the second business day following the submitted payment instructions. The transfer process presents a ledger adjustment in the sending and beneficiary banks, and their correspondents. The SWIFT messages are used by the banks in order to coordinate the cross-border payment and FX spot transaction within the settlement network.

Settlement via corresponding banking network

The correspondent or Vostro Banks X and Y provide the account, credit, clearing, and settlement services for their Nostro or respondent Banks A and B in the local RTGS systems. The respondent banks and their Clients A and B are exposed to the settlement risk in this arrangement. Fig. 2.1 presents the settlement schemes of the cross-border payment and FX spot trade between the clients in Finland and the USA which are designed based on the papers of Harrison (1997), Lidley (2008) and Massarenti (2012).



(a) Transaction from Finland to the US



(b) EUR/USD spot trade

Figure 2.1: transaction between the EU and the US based via corresponding banking
Source: author's own illustration based on Harrison, 1997; Lidley, 2008; Massarenti, 2012

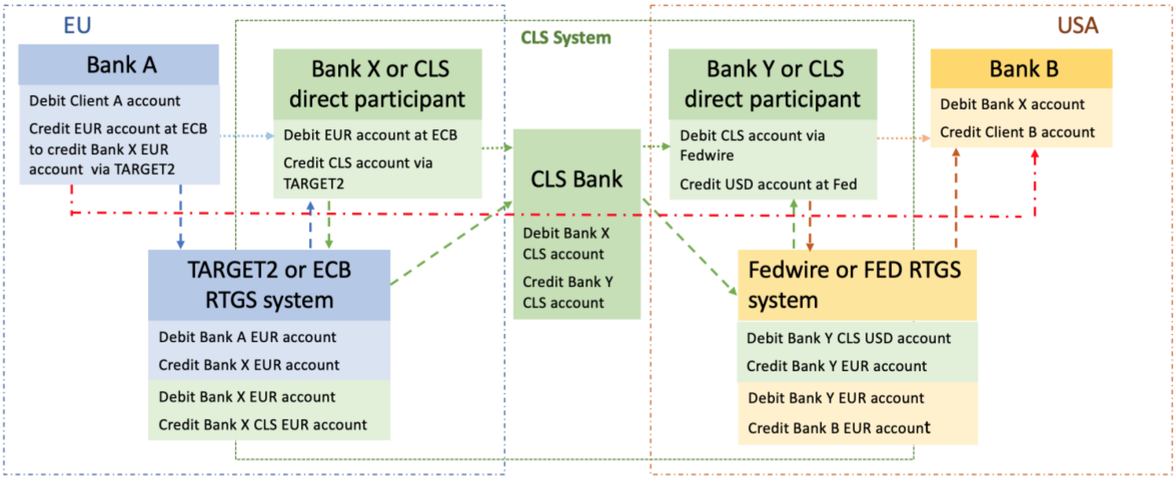
The scheme in Fig. 2.1 (a) illustrates the EUR/USD transaction from the account of Client A at the Bank A in Finland to the account of the Client B at the Bank B in the USA. As the finish bank is not a direct participant of the Fedwire system and does not have corresponding relationships with the Bank B, it needs to contact the correspondent bank of the bank B (bank X) or the branch of the bank B in the EU in order to fulfil the transaction. The transaction is settled and cleared on the Bank A and Bank X accounts in EUR at the ECB via the TARGET2 system. The payment confirmation of this settlement is sent by the bank X to its correspondent in the US or the Bank B. Further the Banks X and B can settle the transaction through mirror accounts of each other at their books and their accounts at the

FED via Fedwire system. At the last step the Bank B credits the incoming funds at the Client B account in USD in the US.

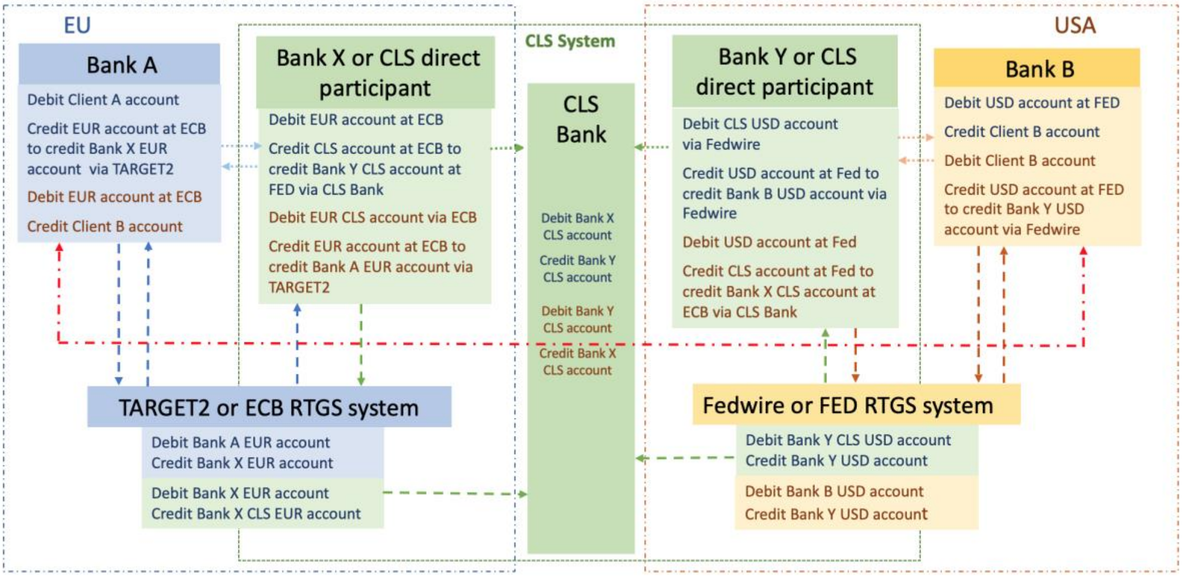
The transaction becomes more complex (Fig. 2.1 (b)) if it is a spot FX trade between the Clients A and B. The payment process of the first leg in EUR is similar to the process of the simple cross border transaction described above. However, in this case the Client B of the US Bank B transfer also a payment in USD (the second leg) to the Client A in Finland. As the Bank B is not the Bank A's correspondent and not a direct participant of the TARGET2 system, it contacts the correspondent bank of the Bank A (Bank Y) in the US. The trade is settled and cleared on the Banks B and Y' accounts at the FED via the Fedwire system. As soon as the funds are credited at the Bank Y account in the EU, it sends the trade confirmation receipt to the Bank A. The Bank A verifies the payment and credits the funds in EUR at the Client A account. As the debiting and crediting does not happen simultaneously in two unrelated correspondents and central bank systems (Fedwire and TARGET2), both clients are exposed to the settlement risk.

Settlement via CLS system

The settlement of the simple cross-border transaction and the FX spot trade via the CLS Bank is summarized and illustrated in Fig. 2.2 using the papers of Lindley (2008) Ganapathy (2014) and CLS (2017). Although the CLS system is applied mainly for the settlement of FX spot, forward and swap trades, the simple cross-border payment can be handled in the following way. The Client A of the Finish Bank A makes a time-critical high-value payment to the Client B's account at the Bank B in the US via the CLS system (Fig. 2.2(a)). In order to perform the cross-border transaction, the Bank A sends the payment instructions to the Bank B and Bank X (or to a direct member of the CLS) via the CLS Third Party Services. The Bank X records it as a currency position for the Bank A and transmits the payment instruction further to the CLS Bank for authentication, matching, settlement, and clearing. As the Bank B is not a direct member of the CLS system, the payment is debited to the direct member of the CLS system or the Bank Y where the Bank B has the Third Party Service agreement. The CLS system provides the payment schedule and the required pay-ins (funding) to the Banks X and Y, and they inform the settlement status to their third parties (the Banks A and B). The Bank X debits the Bank A account and credits its EUR CLS account at the ECB via the TARGET2 system. The CLS Bank debits the Bank X EUR account and credits the Bank Y USD account during the settlement cycle. Later, the Bank Y credits the Bank B's account at the FED via the Fedwire system, so the Client B gets the funds in USD. If the Bank B has an account with the Bank Y, then the funds can be credited already in the settlement cycle.



(a) Transaction from Finland to the US



(b) EUR/USD spot trade

Figure 2.2: transaction between the EU and the US based via CLS
Source: author's own illustration based on Lindley, 2008; Ganapathy, 2014; CLS, 2017

The EUR/USD spot trade (T+2) between the Clients A and B is illustrated in Fig. 2.2 (b). As the Banks A and B (where the clients performed the deal) are not direct members of the CLS system, they need to forward the agreed deal instructions via CLS Third Party Services to their CLS settlement members (the Banks X and Y), where they have agreement with. The Banks X and Y record the payment instructions as currency positions for the Banks A and B correspondingly. The CLS settlement members forward the instructions of the EUR and

USD trade legs to the CLS Bank, and it matches and records them as the Banks X and Y undertakings for the following settlement and clearing process. At the beginning of the settlement day the CLS Bank provides the Banks X and Y with a settlement schedule and the required net funding. The Banks A and B get this schedule and the corresponding net funding requests for their particular deal from the Banks X and Y. The settlement members credit/debit the accounts of their third parties and adjust their CLS accounts at the corresponding central banks in accordance with the received pay-in positions. In the settlement day the CLS sub-currency accounts of the Banks X and Y at the ECB and the FED are blocked for settlement process in the CLS system. It means that both legs (the EUR leg and the USD leg) of the FX spot contract are settled simultaneously in the CLS system. The customers A and B get the corresponding long and short position amounts from the Banks A and B correspondingly by the end of the value date.

2.3 Settlement via Utility Settlement Coin system

At the time of writing, the details of the USC arrangement have not been introduced yet, so its possible implementation is evaluated herein. The limited information from the news and several other proof-of-concept DLT arrangements are applied to define the settlement scheme using USC for further analysis.

Utility Settlement Coin project

The Utility Settlement Coin (USC) project has been initiated by the Swiss bank UBS and the fintech start-up Clearmartics in 2015. By 2017 this initiative has been joined by Deutcher Bank, Santander, BNY Mellon, Barclays, HSBC, State Street, Credit Swiss, and others. The aim of the USC project is to develop “a new, streamlined payment mechanism for institutional purposes, that could potentially replace clearinghouses and other intermediaries, that sits between buyers and sellers of assets” (De Meijer, 2017). The effective process of interbank transactions by means of the USC is supposed to be achieved through the application of DLT and fiat currency (USC), which allow minimizing the risks associated with the traditional settlement frameworks. The new arrangement is supposed to spread across multiple sites, institutions, and countries. The first commercial launch was planned in the end of 2018 (De Meijer, 2017).

The USC, or the applied fiat currency, is supposed to be fully backed by collateral or cash at the custody account of the local central banks, so the settlement and clearing can be free from the credit risk. This fully collateralized digital cash instrument can allow avoiding an impact on the money supply. The USC is supposed to run on a private financial platform built on a permissioned DLT network, so only the authorized nodes or financial institutions are able to validate the funds transfers between each other. The liquidity needs of the system participants in the USC are suggested to be met via money market, where the financial institutions can borrow or lend to the other financial institutions. The settlement and clearing processes between the financial institutions are supposed to be in USC, which allows reducing frictions, speed up the back-office processes, improve capital efficiency, processing time, risks and costs for post-trade processes. (Dalay et al., 2017; De Meijer, 2017)

Settlement via USC system

As technical details of the USC system have not been presented yet, its possible implementation is created and summarized based on the proof-of-concept DLT settlement arrangement of the Jasper Project (2017) and the Project Ubin (Accenture, 2017), and the report prepared by KPMG (2018) for analysis purposes in this thesis.

The USC system is supposed to be dedicated for the wholesale payments between the financial institutions, so its operational model should be based on a permissioned DLT network in order to guarantee data privacy and meet the legal and compliance requirements (Biella and Vittorio 2016; Sontheimer et al., 2017). In accordance with the results of the Jasper Project (Corda-based system), the notary-based DLT network concept is preferable for the USC system with its strict privacy and high transaction bandwidth requirements. In this way each participant of the USC arrangement supports its proprietary ledger, performs and validates transactions, while only the notary and supervisory nodes perform the consensus, manage the reversals, and maintain the database of the shared ledger. The consensus is achieved on the basis of the financial agreement between a party and notary and supervisory nodes. Then notary node, or peer, can support the network participants with the uniqueness of any payment or eliminate the double spending problem actual for the electronic money. The data integrity and authentication of the party signatures can be ensured by the peers as well (Accenture, 2017). The regulator can operate the supervisory node and, thereby, has access to all the transactions and financial agreements (Stark, 2017). The application of the notary concept allows avoiding high computation costs, limited distribution functionality of the public Internet, and low scalability seen in the systems based on the proof-of-work (PoW) protocol, like Ethereum and Bitcoin (Chapman et al., 2017).

As transaction ledger is shared between several nodes in the DLT network, it allows better system integrity and resiliency to cyberattack, accounts reconciliation (Dalal et al., 2017). The bilateral channels can be created in the USC platform to maintain the privacy of transactions and other confidential data (Accenture, 2017).

The payment process can share the common logic or IOU concept, where the settlement combines two phases – claim on the parties, and then netting process to transfer the final – in order to minimize the liquidity needs. The participants of the USC network can submit the trade instructions in the USC system, where the transactions can be processed through validating, uniqueness, and matching cycles before they get settled on the net basis and added to the ledger. The transaction instructions can be submitted via the SWIFT network or a more efficient and fast payment message system. The smart contracts can define the financial relationship and its legal side in every payment and trade (Stark, 2017).

Two schemes can be applied in the settlement systems – survivor or defaulter pays. The survivor scheme is applied usually in the netting systems (e.g., CLS), where in case of the counterparty's default the other solvent participants cover the system losses. This logic of the survivor scheme creates incentive for the system participants to monitor their counterparties.

The defaulter pay scheme is utilized in the gross settlement system, such as the RTGS systems of the central banks. The logic of the defaulter pay scheme is based on the pledge collateral, or prefund, which is released to cover the losses of the other participant in case of this counterparty default or insolvency. This scheme creates the incentive for the settlement system participants to control their exposures and the centralized party to monitor the system. The defaulter pay scheme looks as the most appropriate scheme for the international payment settlement in USC. (Leinonen, 2005)

The central bank RTGS systems can be involved in the settlement process in order to provide the necessary time-critical liquidity and ensure the settlement finality (Marshall, 2017). In the current state the RTGS systems are based on the centralized framework where the central banks manage their particular centralized ledgers. However, the decentralized network is seen as more beneficial for international payments and FX trades, as several drawbacks, like limited operating hours and slow settlement, can be avoided in this case. The collateral and credit limits can be eliminated in the decentralized system via removing the unsettled pending transactions by special funding routine (Nakaso, 2017).

As USC is applied in the cross-border wholesale settlement, the central banks need to ensure deep liquidity in order to meet the fluctuating demand from the settlement parties (Higginson, 2016). In order to limit the strict liquidity requirement on the participants the liquidity-saving mechanism (LSM) or periodic multilateral payments netting can be applied in the USC system. This functionality was tested in the second phase of the Project Jasper via an “inhole/exhole” routine applied for all the registered transactions in the queue. The “inhole” process consists in sending the request for prefunding of net position to all the participants just before the matching of their transactions. When the payment is validated and added to the ledger, the sub-set of payments is cleared on the net basis and the system pays out the resulted balances back to the participant bank accounts in the “exhole” process. The Bank of Canada supported this procedure by collecting the prefunds in its accounts and returning the settlement proceeds after the completing of the matching and clearing cycle (Chapman et al., 2017). The application of the LSM process can reduce liquidity requirements for the participants in the USC network, and, thereby, limit the number of the pending trades due the participants short illiquidity.

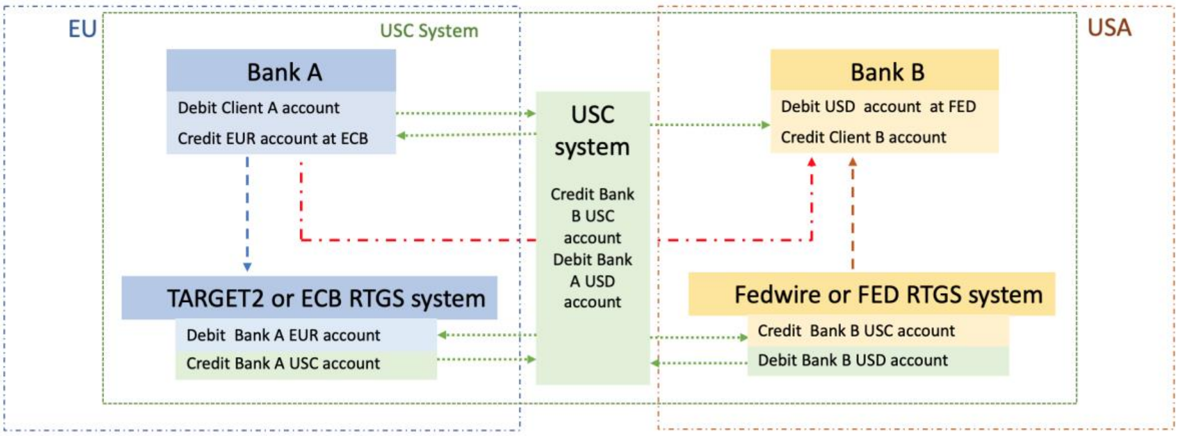
In the DLT arrangements the settlement presents a time interval between the posting the transaction instructions and the recording of both trade legs on the ledgers, where verification and confirmation happen in between (ECB and BJ, 2018). The settlement finality should be defined in the legal structure (as a claim on central bank) and to be immutable (without an ability to undo). The clear definition of settlement finality is required to avoid legal issues and limit the uncertainty in case of counterparty default and operational issues. For example, in Jasper project the settlement finality occurred at the point “when a bank’s wallet is updated on the Distributed Ledger (DL)” (Chapman et al., 2017). The immutability of the settlement and operational settlement finality can be supported by certain consensus mechanism. For example, Ethereum and Bitcoin platforms utilize the proof-of-work (PoW) consensus mechanism, where the settlement finality presents a time interval between the points when the transaction parties get request to agree on the ledger state via consensus process, and the shared ledger is agreed and updated. This probabilistic settlement finality causes uncertainty in the account state and, thereby, in the parties’ rights and obligations. The PoW is also vulnerable to a 51 percent attack that can alter or reverse the payment result. The Corda platform utilizes the notary function to commit the transaction after verification and completion. This way allows protecting the system participants' funds from a compromise or a malicious activity. The regulatory node or system operator is supposed to control and check that the known participants follow the system rules. The central banks can present notary and supervisory roles in the USC system, so the transactions collected and stored on the shared ledger can be trustable and present a legal basis. As the deterministic finality is preferred for the settlement systems, the *mining* should be restricted to one node (ECB and BJ, 2018). In this way the notary and supervisory nodes assure the settlement finality, and, thereby, they help to avoid the liquidity and credit risks for the system participants. The network protocol and smart contract can define simultaneous settlement and recording the transaction on the ledger. (Mills, 2016; Dalal et al., 2017; Chapman et al., 2017)

USC system settlement scheme

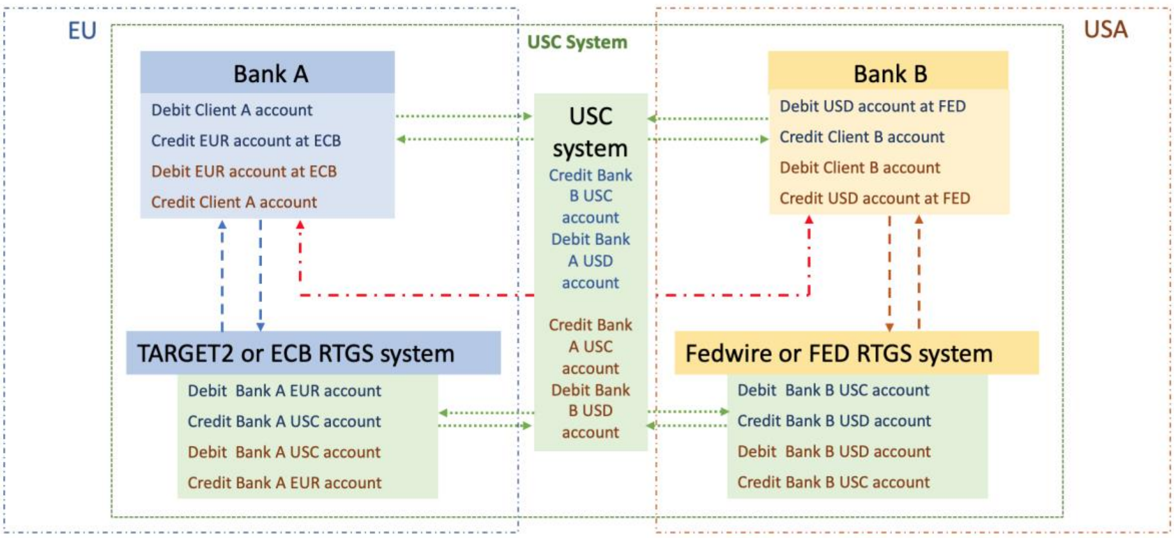
In accordance with the discussion presented above the settlement schemes shown in Fig. 2.3 can be outlined for a simple cross-border trade and FX spot trade in the USC system. The USC system consists in a network operator, the banks operating party nodes, and the central banks performing notary and supervisory nodes. The trusted set of the fixed notaries decides whether the payment is succeeded or failed and, thereby, plays a validator role. The Banks A and B can settle the payments in USC using their accounts at the corresponding central banks. In accordance with Ripple experience (Schwartz, 2018), the payer's and receiver's properties need to be standardized in order to achieve interoperability within the network. The common Secure Hash Algorithm (SHA)-256 hash-locks crypto conditions can be implemented in the new network for signing the payment instructions to ensure high security standards.

The originating Bank A and beneficiary Bank B have settlement accounts with the ECB and the FED correspondingly. The USC platform presents an ancillary and shared system for all the participating central banks in order to settle the cross-border transactions between the financial institutions under the corresponding jurisdictions. The USC system is dedicated to issuance, exchange, cancel, and do redemption of USC. The USC platform can operate 24/7 and in parallel with the participating RTGS systems.

The financial institutions operating the party node settle peer-to-peer cross-border transactions and FX trade via the USC platform. In case of the simple cross-border payment the payer (or Client A) initiates the transaction by instructing the Bank A with the payment details. The Bank A confirms the payment details, reserves the funds at the Client A's account and informs the receiver Bank B. As soon as the confirmation and screening processes are completed, the Bank A transmits the payment instruction signed digitally with a private cryptographic key to the USC system for further settlement.



(a) Transaction from Finland to the US



(b) EUR/USD spot trade

Figure 2.3: transaction between the EU and the US based on a DLT-based system
Source: author's own illustration based on KPMG, 2018

The USC system confirms the payment details and sends it further to the notary nodes (ECB and FED systems) for validation and uniqueness checks. In order to transmit the funds to the beneficiary Bank B via the USC platform, the Bank A needs to ensure that its USC account contains the required funds, or otherwise, these funds need to be issued by the ECB based on the pledged euros at its collateral account. As soon as the ECB and FED systems are satisfied and have signed the payment orders digitally, the transaction is ready for settlement in the USC system. The USC system performs matching for the payment instruction and records it on its ledger. After the matching process, the settlement proceed is transferred to the USC account of the Bank B at the FED. Later the Bank B credits the funds in USD to the Client B's account by debiting its USD account at the FED.

Fig. 2.3 (b) illustrates the EUR/USD spot trade between the Client A in Finland and the Client B in the US. When the Clients A and B agree and sign the trade details, they initiate the contract settlement by contacting their Banks A and B. The Banks A and B are operating the party nodes in the USC network, so they validate the payment details and broadcast the payment instruction signed digitally for further settlement in the network. In order to fund the USC accounts, the Banks A and B contact their local central banks to generate and credits the funds against the pledged corresponding currencies (EUR and USD) at the collateral accounts. The USC platform performs the necessary validations and sends the deal instruction to the ECB and the FED for uniqueness and validation checks. As soon as the deal details and the accounts of the Banks A and B meet the requirements, the notary nodes add their digital signatures to the transaction requests and transmit their approvals to the USC system operator. The deal legs are settled by a special matching algorithm or offsetting of multilateral payments in order to request just the net settlement obligations from the party nodes. The ECB and FED are responsible to transfer or receipt the net amounts in USC for their members accounts during the matching cycle in the USC platform. Later the Banks A and B credits the deal proceeds in the corresponding local currencies to the Clients A and B' accounts.

2.4 Data

The settlement process of the cross-border trade depends on many conditions, such as internal procedure in the intermediaries, local payment patterns, finality rule, operating hours in the local payment systems, and connection between payment systems of different countries.

The settlement risk exposure and duration are the main parameters to assess and compare the settlement processes via correspondent banks, the CLS, and the DLT-based arrangement. In order to estimate the settlement risk duration and exposure for the EUR/USD payments, the settlement processes are split into the settlement sub-processes using the information from several different sources (Harrison, 1997; Lindley, 2008; Massarenti, 2012; Massarenti et al., 2013; Ganapathy, 2014; CLS, 2017; KPMG, 2018). Each sub-process is investigated in details aiming to assess its impact on the overall settlement risk exposure and duration. Several scenarios of the settlement process are constructed in order to analyze the impact of the initiation time by the client, behavior of the intermediaries, and the effect of the time zone difference (7 hours) between Finland and the US on the settlement risk duration.

The settlement delays, overall payment process, and cut-off time requirements for incoming and outgoing payments are collected from the web-sites of several banks (Nordea, HSBS, Citi), the RTGS payment systems (TARGET2, Fedwire), and the CLS. The papers of Lindley (2008), Massarenti (2012), Tanai (2008) are applied in order to get the settlement delay data in the TARGET2 and Fedwire systems. The settlement delays in the DLT-based system are assumed based on the data presented in the papers of Neto et al. (2017), Natarajan et al. (2017) and KPMG (2018).

In accordance with the research of Tanai (2008), the settlement of the FX trades and cross-border payments is done usually on ‘the best effort’ basis in many financial organizations and this information is rarely documented in the financial institutions. In this thesis I assume the settlement delays in the payment intermediaries as the listed in Table 2.

Table 2.2: Settlement delays and average cut-off times in payment intermediaries
Source: CITI (2018); ECB (2018); FED(2018); Nordea (2018); HSBC(2018); Ulster Bank (2018); Neto et al. (2017); Natarajan et al. (2017); KPMG (2018)

	Cut-off time	Settlement delay or lag
Traditional settlement system		
Bank in Finland	16:00 CET for incoming and outgoing payments	90-120 min
Correspondent of US Bank in the EU	17:00 CET for outgoing 13:00 CET for incoming	90-120 min
Correspondent of EU Bank in the US	13:00 CET for outcoming 17:00 CET for incoming	90-120 min
Bank in the USA	13:00 CET for outgoing 22:15 CET for incoming	120 min
TARGET 2	18:00 CET	10-30 minutes
Fedwire	00:00 CET	10-30 minutes
Swift message	-	10 min
DLT-based settlement system		
Notary node	-	10 min
Party node	16:00 CET/22:15 CET	30 min
System operator	-	1 min/5 min

In accordance with the papers of Massarenti et al. (2013) it takes about 5-30 min for the TARGET2 system to settle the payment instruction, if the Banks have enough liquidity at their settlement accounts at the ECB. The settlement lag is about 15-30 min before 12 CET and after 15 CET, while only 5 min between 12 CET and 15 CET. As the exact value for the settlement lag in the Fedwire system has not been found in the research and technical literature, the settlement lag of the TARGET2 system is considered for the Fedwire system due to their similar settlement schemes.

The settlement lag of 60-180 min needs to be considered for processing, confirmation, and screening of the high-value payment details in the initiator and beneficiary banks in order to submit it further to the settlement with finality in the RTGS system (Ulster Bank, 2018). As the beneficiary bank needs to process the payment, reconcile the accounts, and confirm the details, its settlement lag is assumed as 120 min. The commonly used SWIFT messages are considered as the main payment instruction method in all the settlement set-ups under analysis.

The Swift messages are applied as a tool to provide payment instruction (MT103, MT202COV), settlement instruction (MT304/300), end of day account (MT940/MT950) and intra-day balance statements (MT941/MT942). The cover method of cross-border payment transfer is applied in the analysed schemes, as it is assumed that the payer bank has the SWIFT bilateral arrangements or Relationship management Application (RMA) with the beneficiary and correspondent banks. Although there is no official information how long the SWIFT message is processing in the banks before it sent, the settlement lag of 10 min is assumed for this process in accordance with several blogs (Quora, Forums).

In the DLT-based system the settlement lag of 30 min is assumed for the initiator and beneficiary banks, as they are required to perform the time-consuming customer screening process (Natarajan et al., 2017). In accordance with Neto et al. (2017), the notary nodes or the central bank require about 5 min in order to verify the submitted party profile and account statement, and to request the needed liquidity. The matching process of the endorsed and confirmed transaction is assumed to last for about 10 minutes. These assumptions look reasonable in accordance with the testing results of the ECB and Bank of Japan (2008) where 97% of settlement time was spent on transaction verification and its commitment to the ledger.

3. Analysis and results

The international transactions do not become final (unconditional and irrevocable) until several hours or even days elapsed after they had been initiated. This chapter presents an investigation of the settlement risk duration and exposure for the simple cross-border trade and FX spot trade which are settled via CB, the CLS system and the DLT-based arrangements.

3.1 Settlement risk of simple cross-border payment and FX trade in corresponding banking network

The settlement of cross-border trade and FX deal via CB arrangements is associated usually with a considerable settlement delay or a time interval between the initiation of payment message and its final arrival to the beneficiary. This settlement lag can be split into several phases – handling payment in a sending bank, TARGET2, a correspondent bank, Fedwire, and a receiving bank.

Simple cross-border payment

Fig. 3.1 illustrates a detailed scheme for the settlement of the simple cross-border payment from Finland to the US via a correspondent bank. At the first step the Client A instructs the Bank A (where the Client A has the account) in Finland to transfer a payment to the Client B's account at the Bank B in the US on the same day T. The Bank A spends on average 90 min to confirm and screen the payment instruction, and 10 min to send it by the SWIFT MT130 message (customer payment) to the Bank B and by the SWIFT MT202COV to the Bank's B correspondent in the EU (Bank X) (Ulster Bank, 2018). The SWIFT MT103 message is applied for the customer fund transfer messages, while the SWIFT MT202 (MT202COV) is dedicated for financial institutions transfers. The MT202COV allows sending the funds and information separately compared to the SWIFT MT202 message (only fund message), where the originator and beneficiary details are missing. The SWIFT MT202COV are applied widely since 2009 in order to ensure AML, ATF, and sanction compliance controls in the financial institutions (Alexander et al., 2010; KPMG, 2018).

In order to settle the payment instruction with the correspondent Bank X, the Bank A sends the SWIFT MT202 or MT204 message to the TARGET2 system. At this point the Client A's exposure to the settlement risk starts, as the cancellation of the payment instruction is impossible after the confirmed payment instruction in the Bank A (SC, 2018; Ulster Bank, 2018). In accordance with Galbiati and Soramäki (2015), the payer bank (Bank A) may have an initiative to delay the settlement in the TARGET2 system in case of the limited liquidity at its settlement account at the ECB, or in order to optimize its liquidity usage. This behaviour of the bank is permitted as long as the funds are received on the same business day as agreed in the payment instructions. In case of no agreed value date the payer's bank is obligated to credit the funds at the payee's account "no later than the business day following the acceptance of the payment instruction" in accordance with the Payment Service Act (Finanssivalvonta, 2018). However, this delay amplifies the Client A's exposure to the settlement risk, as the exposure duration may last for more than 24 hours (see Table 3.1).

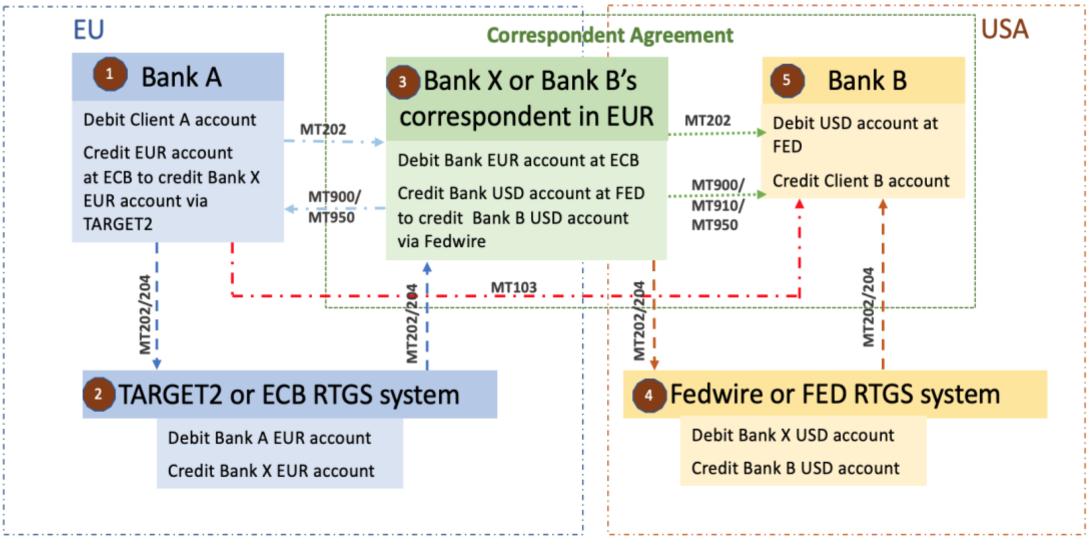


Figure 3.1: settlement of cross-border payment via corresponding banks
Source: author's own illustration based on KPMG, 2017

At the second step, the TARGET 2 system settles the payment by debiting the Bank'A account and crediting to the Bank X's account with the instructed funds. In accordance with the papers of Massarenti et al. (2013), it takes about 20 min for the TARGET2 system to settle the payment instruction if the Bank A have enough liquidity at the settlement account at the ECB. At the next step the correspondent of the Bank B (Bank X) handles the payment instruction received by the SWIFT MT202COV from the Bank A and arranges the payment central settlement by sending the SWIFT MT202COV to the Fedwire system. The settlement lag in the Bank X is impacted by the regulatory compliance screening process of the payment details (AML/CFT), the time difference in the operating times in Finland and the USA, and also the Bank X's initiative to settle fast based on the liquidity state of its account at the FED. In accordance with the procedures of the Ulster Bank (2018) the confirmation and screening process takes about 90 min.

The step 4 is the settlement at the accounts of the Bank X and the Bank B at the FED via the Fedwire system. The settlement lag at the Fedwire system can be assumed as 20 min as in the TARGET2 system. At the last step the beneficiary Bank B reconciles and screens the payment details, and credits the Client B account at latest in 120 minutes at the latest after the payment is credited at its account at the FED.

FX spot trade

Fig. 3.2 presents the settlement scheme for the FX spot contract under analysis. The Client A in Finland purchases spot USD from another Client B in the US where the settlement process of this trade is facilitated by the Bank A (Finland) and the Bank B (the US). The value date for FX spot contract is T+2 (or V), where T is the trade date and V is the value date. At the first step the Bank A confirms the trade details, debits the account of the Client A, and sends the trade instruction by the SWIFT MT103 message to the Bank B and the SWIFT MT202COV message to the correspondent of the Bank B (the Bank X) at the EU. At this point the Client A is started to be exposed to the settlement risk, as the EUR leg of the FX spot (sold currency) is booked at his (her) account and confirmed with the Bank X, while the USD leg (bought currency) is still in process to reach the Client A’s account. In accordance with Lindley (2008) the Client’s A exposure to the settlement risk depends on the time when the trade instruction is sent by the Bank A to the Bank X and the deadline for its cancellation based on the agreement between the Bank A and the Bank X. The settlement risk exposure of the Client A starts usually on the next day after trade day at the earliest or several hours before the local RTGS system opens on the value day at the latest (Lindley, 2008).

On the second day after the agreed contract (the value day) the preliminary prepared and sent payment instruction of the Client A is processed in the accounts of the Bank A and Bank X at the ECB via the TARGET2 system (step 2). The settlement lag of 20 min can be assumed for the central settlement. As soon as the Bank X receives the funds from the Bank A, it verifies and screens the payment instruction, credits the funds to the Bank B’s account at the FED via the Fedwire system, and sends the payment confirmation by the SWIFT MT910 or MT950 to the Bank B (step 3). The settlement lag of 90 min can be assumed for the Bank X in order to handle and perform the regulatory compliance screening of the Client A’s payment details. However, the Bank X may delay the payment before the last operating hours of the Fedwire system assuming the cut-off time for incoming payments in the Bank B. The main reason for this additional delay can be a desire of the Bank B to optimize the usage of high-cost liquidity at the FED (Lindley, 2008). As soon as the EUR leg funds are credited at the Bank B account at the FED, it can perform the required verifications and reconciliation and finally credits the Client B's account with the received funds.

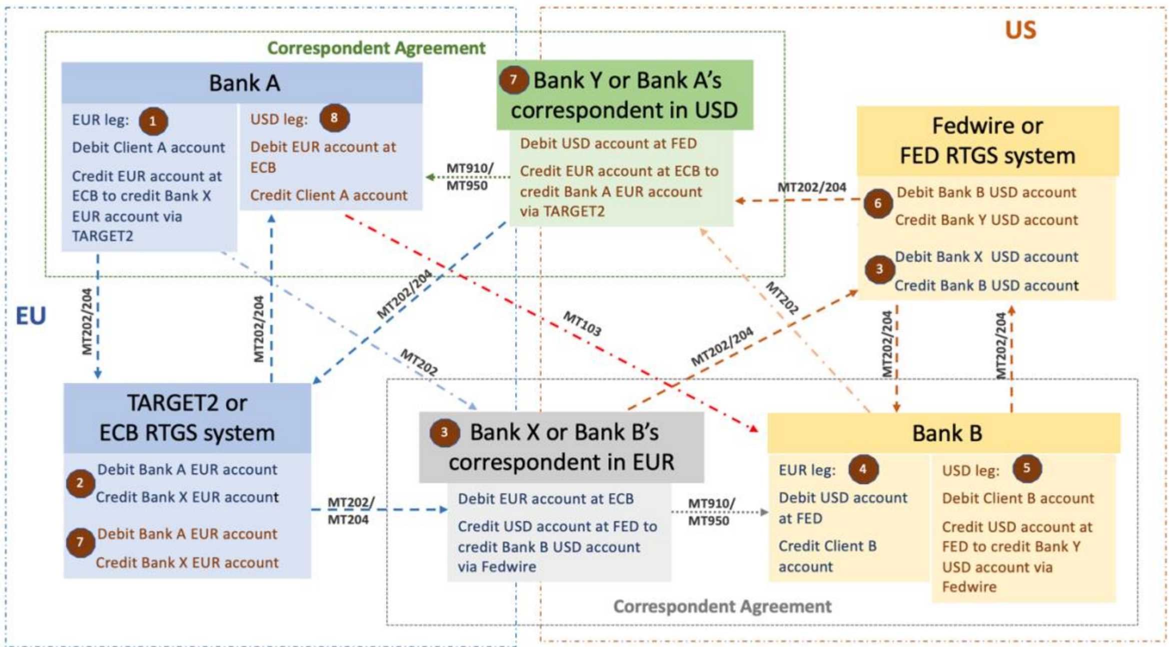


Figure 3.2: settlement of FX spot trade via corresponding banks
Source: author's own illustration based on Lindley, 2008 and KPMG, 2018

In parallel with the above process, the Bank B initiates the settlement of the USD leg of the trade in the US (step 5). As the Bank B does not have a direct access to the TARGET2 system in the EU, it sends the payment instruction by the SWIFT MT202COV to the Bank's A correspondent in the US (the Bank Y) and by the SWIFT MT300 to the Bank A before the value date. At the same step the Bank B debits the Client B's account at the own books in order to provide the payment further. On the value date or the day before it the agreed payment instructions from the Bank B are settled at the Bank B and Bank Y' accounts at the FED via the Fedwire system (step 6). In order to deliver the payment on the value date (Finnish time) the Bank A needs to submit the payment instructions by the SWIFT MT300 to the Fedwire system in the early morning of the value day on the latest due to 7-hours time zone difference in Finland and the US.

When the funds are received at the Bank Y's account, it credits the funds to the Bank A's account at the ECB via the TARGET2 system and sends the payment confirmation by the

SWIFT MT910 or MT950 to the Bank A. The SWIFT MT910 message is the credit message, while the SWIFT MT950 is the end of the day statement message. It means that the Bank A can be aware of the incoming payment quite late on the value day if it receives the confirmation by the SWIFT MT950 instead of the real-time confirmation by the SWIFT MT910. In accordance with the SWIFT research, only "44% of cross border payments exchanged over Swift generate a real-time confirmation of debit and credit (MT900/910)" (SWIFT, 2017). At the last step the Bank A reconciles the accounts, screens the payment details and credits the funds to the Client's A account later on the value date (or in 2 hours after the payment confirmation on the average).

Settlement risk duration and exposure

Table 3.1 lists the settlement lags at each step of the settlement processes for the cross-border payment and the FX spot trade described above. In the case of the simple cross-border trade, it is assumed that the Client A submits the payment instruction to the Bank A at 8:00CET (Case 2), at 15:00CET (Case 3) and at 16:30CET (Case 1). The average cut-off time for the outgoing payment instruction to be received by the payee on the same value day is 16:00 CET in Finland, so the payment in Case 1 can be settled with the finality only in the next day, and therefore, it has the longest *settlement risk duration for the Client A* (28 hours). When the Client A instructs the Bank A just before its cut-off time for the outgoing payment, the settlement risk duration for the Client A can be almost two times less (5.2 hours) compared to the time if he or she forwards the payment instruction in the morning (12.2 hours). It is associated with the fact that the correspondent banks are prone to delay the payments and settle the payments in the central systems later in the day. As the banks have limited liquidity at their accounts at the ECB and the FED, they may postpone the payments until the end of the day in order to avoid taking the intra loans and to cover the obligations by the incoming funds during the day.

The settlement risk of the EUR/USD spot trade is analysed for the Client A and the Client B. As it was described above, the deal counterparties' banks initiate the settlement on the day before the value day (V-1) or on the value day (V). These two scenarios are investigated.

Table 3.1: Settlement steps and its average duration in transactions via correspondent banking arrangement

Source: Author's own calculation

Settlement step in cross-border payment and FX spot EUR-leg (*USD-leg*)	Cut-off time for outgoing/ incoming payment	Technical settlement delay	Settlement lifecycle of EUR/USD cross-border payment	EUR-leg of FX spot trade (Client A)	USD leg of FX spot trade (Client B)
Handling payment instructions in Bank A (*Bank B*) from Client A (*Client B*) and sending MT202COV to Bank X (*Bank Y*) and MT202 to TARGET2 in the EU (*Fedwire in the US*)	16:00CET[1] (*13:00CET[6]*) -	90 min[6] 10 min	1. 16:30CET on day (T-1) -> **processed by 18:10CET on day T and** sent at 16:40CET on day T 2. 8:00CET on day T -> **processed by 09:40CET on day T** and sent at 16:40CET on day T 3. 15:00 on day T -> **processed and sent at 16:40CET on day T**	1. 12CET at (V-2) -> **processed at 15:00CET on day (V-1)** 2. 12CET at (V-2) -> **processed at 06:00CET on day V**	1. 12CET at (V-2) -> **processed at 15:00CET on day (V-1)** 2. 12CET at (V-2) -> **processed at 11:00CET on day V**
Handling fund transfer between Bank A (*Bank B*) and Bank X (*Bank Y*) via TARGET2 (*Fedwire*)	07:00-18:00 CET[3] (*03:00-00:00 CET[4]*)	5-30 min	1/2/3. 16:40CET on day T -> 17:00CET on day T	1. 15:00 -> 15:20CET on day (V-1) 2. 06:00 -> 07:20CET on day V	1. 15:00 -> 15:20CET on day (V-1) 2. 11:00 -> 11:20CET on day V
Handling payment instructions in Bank X (*Bank Y*) and sending MT202COV to Bank B (*Bank A*) and MT202 to Fedwire in the US (*TARGET2 in the EU*)	17:00CET[2] *(13:00CET[6])* -	90 min[6] 10 min	1/2/3. 17:00CET on day T -> 19:40CET on day T	1. 15:20CET on day (V-1) -> 13:00CET on day V 2.1. 07:20-> 13:00CET on day V 2.2. 07:20-> 19:40CET on day V	1. 15:20CET on day (V-1) -> 07:00CET on day V 2.1. 11:20 -> 13:00CET on day V 2.2. 11:20 -> 15:00CET on day V
Handling fund transfer between Bank X (*Bank Y*) and Bank B (*Bank A*) via Fedwire (*TARGET2*)	03:00-00:00 CET[4] (*07:00-18:00 CET[3]*)	5-30 min	1/2/3. 19:40CET on day T -> 20:00CET on day T	1. 13:00-> 13:20CET on day V 2.1. 13:00->13:20CET on day V 2.2. 19:40->20:00CET on day V	1. 07:00 -> 07:20CET on day V 2.1. 13:00->13:05CET on day V 2.2. 15:00->15:20CET on day V
Handling payment to Client B (*Client A*) in the Bank B (*Bank A*)	22:15CET[5] (16:00CET[6])	120 min	1/2/3. 20:00CET on day T -> **22:00CET on day T**	1. 13:20 -> **15:20CET on day V** 2.1. 13:20 -> **15:20CET on day V** 2.2. 20:00 -> **22:00CET on day V**	1. 07:20->**09:20CET on day V** 2.1. 13:05->**15:05CET on day V** 2.2. 15:20->**17:20CET on day V**
Total settlement risk duration (exposure) for Client A and Client B	-	-	**1. 28 hours (N)** **2. 12.2 hours (N)** **3. 5.2 hours (N)**	**1. 24.5 hours (N^A+N^B for 18-24.5 h)** **2. 9.2 hours (N^A+N^B for 9-9.2 h)** **3. 16 hours (N^A+N^B for 11.2-16 h)**	**1. 18.2 hours (N^A+N^B for 18.2 h)** **2. 4.05 hours (N^A+N^B for 4.05 h)** **3. 6.20 hours (N^A+N^B for 6.2 h)**

[1]Nordea (2018); [2]CITI (2018); [3]ECB (2018); [4]FED(2018); [5]HSBC(2018); [6]Ulster Bank(2018)

The results in Table 3.2 demonstrate that the initiation of the settlement process on the day before the value day increases the *Clients A and B settlement duration* from 9-16 hours to 24.5 hours for the EUR leg and from 4-6.2 hours to 18.2 hours for the USD leg. This result is associated with the fact that the payers' banks may deliver the settlement instruction late in the day before the value day in order to use the liquidity collected at their accounts at the ECB and the FED during the day, and therefore, the payment can be stacked in the system until the next day. The other reason is related to the intermediaries, or correspondent banks, which prefer to save costs on the SWIFT messages and liquidity in the RTGS systems, so most probably the payment settlement is postponed by them until the late hours on the value day (Lindley, 2008). In accordance with the analysis results (Case 2.1 and Case 2.2), the Clients A and B' settlement risk duration can increase by 50-75% due to the above-mentioned reasons.

The Client A has 4 hours longer settlement risk duration than the Client B in all the cases due to the time zone difference between Finland and the US. The time zone difference plays against the counterparty in the earlier time zone in the FX spot contract. The Bank A is committed to initiate the central settlement (or sell the currencies) earlier in the value day than the Bank B needs to submit the bought currencies in order to deliver it on the same value day.

The *settlement risk exposure of the Client A* (nominal amount of payment) is constant during the whole settlement duration in the case of the simple cross-border payment. However, the *settlement risk exposure of the Clients A and B* fluctuates during the settlement time in the case of the FX spot trade. Both Clients have twice exposure (nominals of the bought and sold legs) during 3-24.5 hours in the settlement period. The settlement exposure can be cut possibly to single nominal amount for the Client B by finding the correspondent with the later cut-off time for the outgoing payment, and thereby, settling the payment instruction later on the value date. However, it increases the risks of unsettled transaction on the value day, and, therefore, amplifies the vulnerability of the whole settlement system. The Client A in the earlies time zone can't avoid the settlement risk exposure in the studied deal.

3.2 Settlement risk of simple cross-border payment and FX trade via CLS arrangement

The CLS system is dedicated to settle the FX trades in order to minimize the settlement risk exposure of the trade counterparties. In this section, the settlements of a simple cross-border payment and an FX spot trade via the CLS system are investigated in order to assess the settlement risk and exposure of the Clients A and B.

Simple cross-border payment

Fig. 3.3 presents a detailed scheme of the cross-border high-value payment settlement via the CLS system. The Client A instructs the Bank A in Finland (where he or she has an account) to arrange a high-value payment to the Client B's account at the Bank B in the US latest on the next business day. At the first step the Bank A processes the payment instruction of the Client A by confirming and screening the payment details, debiting the Client A's account, and forwarding the SWIFT MT300 message to the receiver Bank B and the SWIFTNet MT304 message to the CLS module in the Bank X. This step can take about 90 min for the Bank A to confirm the payment details and initiate the settlement (Ulster Bank, 2018). When the Bank B receives the payment order for its Client B, it needs to instruct its CLS settlement member by the SWIFTNet MT304 message in order to get the fund transfer in the agreed settlement session. As the Banks A and B are assumed not having the accounts at the CLS Bank, they need to arrange the payment settlement via the CLS third-party agreements with the CLS settlement members (the Banks X and Y).

At the step 2 (Fig.3.3), the Banks X and Y confirm the received payment instruction, make cover control of their third parties, and transmit the payment instruction by SWIFTNet MT304 message further to the CLS Bank for the authentication, matching, settlement and clearing. In accordance with Hoflich (2011), the CLS settlement members tend to forward the payment instruction within 30-40 min on the agreed trade or instruction receiving from their third parties. However, the Banks X and Y need to ensure that the SWIFTNet MT304 messages are submitted and matched no later than 06:30 CET in the value date in order that the CLS is able to settle them on the same day (Mustich, 2016). As soon as the CLS system authenticates and matches the payment instructions from the Banks X and Y, it sends the matching status info (matched/unmatched/rescinded) to the Banks X and Y, and stores the matched instructions until the settlement cycle starts. The Bank A and B can be updated with the transaction status via CLS web access or by the SWIFT MT396/MT394 messages from their CLS settlement members (Nordea, 2018). In accordance with the CLS principles (Mustich, 2016), the Client A may amend or rescind the payment instruction on a unilateral basis only before 00:00CET on the settlement day when the initial pay-in schedule (IPIS) is issued. It means that the 00:00 CET can be considered as the initiation of the settlement risk for the Clients A and B (Tanai, 2008).

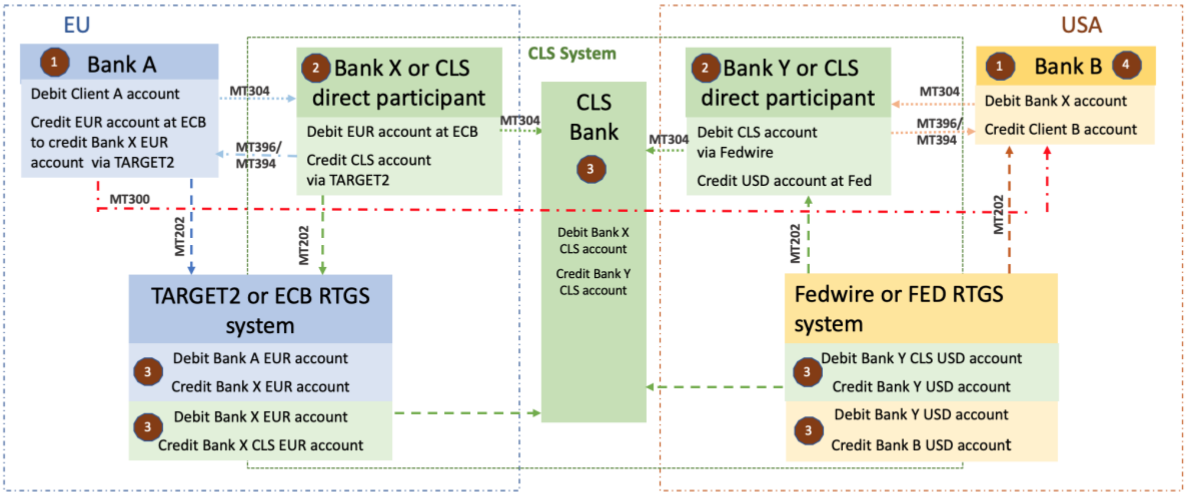


Figure 3.3: settlement of cross-border payment via CLS system
Source: author's own illustration based on Lindley, 2008 and KPMG, 2018

At 00:00 CET the CLS system forwards the IPIS to the participating settlement members, so the Bank X (short position) and the Bank Y (long position) can adjust their currency CLS accounts at the ECB and the FED correspondingly for further settlement (step 3). As the CLS applies netting on the submitted payment instructions per each settlement member, the resultant payment obligations may be about 5% of gross value for all the submitted payment instructions by the Banks X. The Banks X and Y forward the payment instructions by the SWIFT MT202 to the ECB and FED in order to debit/credit the required net funds to their own CLS accounts before these accounts are blocked by the CLS at 06:00CET. At the same time the settlement members credit/debit the accounts of their third-parties at their own books. If the Banks A and B do not have accounts with the settlement members, the funds are credited/debited on their local central bank accounts before or later on the value day by forwarding the SWIFT MT202COV messages to the TARGET2 and Fedwire systems. In this way the settlement members (Banks X and Y) take on the settlement risk on behalf of the Banks A and B during the CLS settlement cycle (IMF, 2010). However, it should be pointed out that the Clients A and B are still exposed to the settlement risk, as the Client B is debited with the funds only later on the value day. It can be assumed that the TARGET2 and

Fedwire systems confirm and process the payment instructions between the accounts of the Banks A and X, and the Banks B and Y during a time period of 5-10 min (Massarenti et al., 2013).

The period between 00:00CET and 06:00CET is dedicated for in/out swap processes and matching of additional transaction details, so the CLS system posts the revised pay-in (funding) schedule and issues Central Banks pay-in reports at 06:30CET. The CLS system blocks the accounts of the participating direct members at 06:00 CET in order to start the settlement process at 07:00 CET. The CLS Bank debits the Bank X EUR account and credits the Bank Y USD account during the settlement cycle between 07:00 CET and 09:00 CET (step 4). The settlement and funding are running alongside between 07:00 and 09:00 CET, where the pay-in and pay-out can be completed by 12:00 CET. In order to minimize the liquidity pressure on the settlement members (as the transaction are settled on the gross basis), the pay-ins are allowed to be done in five tranches. However, the investigation of Kobayashi et al. (2007) demonstrates that the settlement members tend to provide the pay-ins in the period between 08:30 CET and 09:30 CET, or 30 min prior the deadline in the CLS system. At the end of the settlement and funding cycle, the CLS system informs the Banks X and Y with the settled status of their payment.

At the fourth step, the Bank B confirms the fund transfer from the Bank Y at its account within the Bank B. If the Bank B does not have an account with the Bank X, the funds are credited to its FED account via the Fedwire system during the value day. As soon as the Bank B gets the funds, it performs regulatory compliance screening process of the payment details and credits the funds at the Client's B account in about 120 minutes. This time can be considered as the end of the settlement risk for the Clients A and B.

FX spot trade

The FX spot trades account for a significant share of the daily traded volume submitted to the CLS system (CLS, 2018). Fig. 3.4 illustrates the settlement steps for EUR/USD spot trade between the Client A in Finland and the Client B in the US. At the first step, the Clients A and B perform the FX deal using the services of the Banks A and B correspondingly where they have accounts. As the banks of both clients are assumed as not direct members of the CLS system, they need to forward the agreed deal instructions by the SWIFTNet MT304 messages via CLS third-party services to their CLS settlement members

(Banks X and Y). The CLS Client Services are operating 24 hours per each banking day, so there is not cut-off for the payment messages submission at the settlement members (UBS, 2018). However, the payment instructions need to be received and matched by the CLS system until 06:30 CET on the value day, so the settlement cycle starting at 07:00 CET can process them on the same day (Mustich, 2016). It can be assumed that the Banks A and B send the agreed deal instructions simultaneously to the Banks X and Y' CLS Client Services at 15 CET on the settlement day (V-2).

In accordance with the CLS principles, the Clients A and B may amend or rescind the payment instructions on a unilateral basis before the IPIS posted at 00:00 CET or on a multilateral basis before the revised pay-in schedule (RPIS) issued at 06:30 CET on the settlement day (Mustich, 2016). It means that the 00:00 CET can be considered as the initiation of the settlement risk for the Clients A and B (Tanai, 2008).

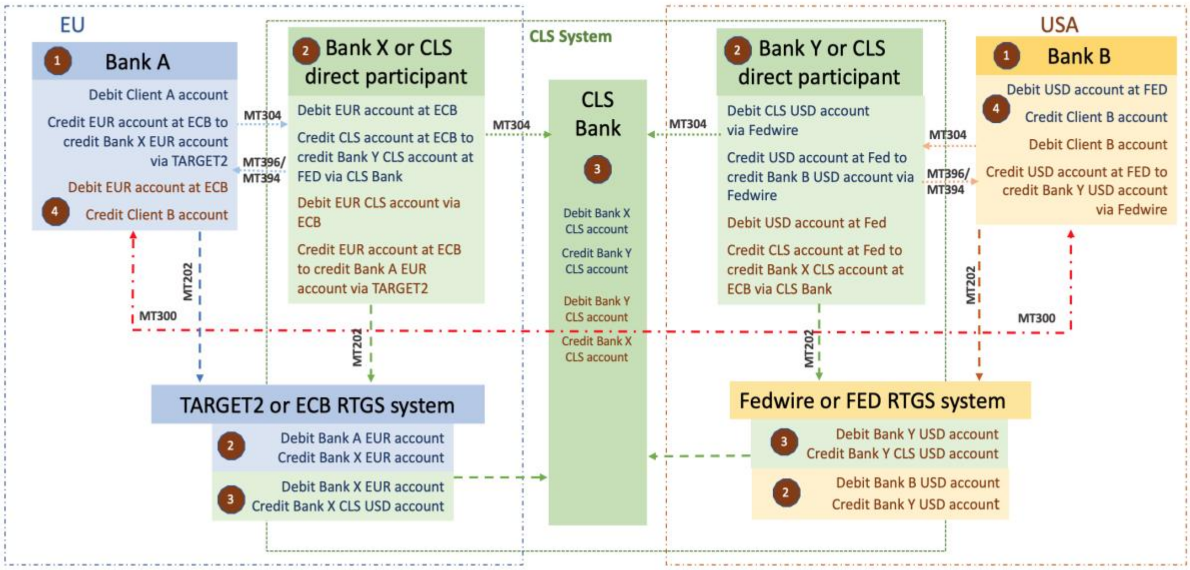


Figure 3.4: settlement of FX spot trade via CLS system

Source: author's own illustration based on Lindley, 2008; Mägerle and Maurer, 2009; KPMG, 2018

At the second step the Banks X and Y confirm the payment instructions, register them as the currency positions for the Banks A and B, and transmit them by the SWIFTNet MT304 messages further to the CLS system for the authentication, matching, settlement, and clearing. In accordance with Hoflich (2011), the CLS system gets the deal instructions in about 30-40 min after the deal captured at the same settlement day. The CLS system authenticates and matches the deal instructions of both clients, updates the settlement members with the new transactions statuses ("matched"), and queues the matched trade instructions before the value day. The Banks X and Y update the Banks X and Y with the transaction status via the CLS web access or by the SWIFT MT396/MT394 messages (Nordea, 2018).

On the value day the CLS system forwards the IPIS with the net funding required to all participating settlement members at 00:00 CET, so the Banks X and Y can adjust their liquidity needs using the in/out swaps, bilateral agreements, and other means. The settlement members can forward the adjusted and new payment instructions before 06:30 CET when the CLS system posts the RPIS and the final net positions. In accordance with the IPIS and further liquidity adjustments the Banks X and Y send the SWIFT MT202 to the ECB and the FED in order to debit/credit the Banks A and B account at its own books and credit their own CLS accounts via the TARGET2 and the Fedwire (step 3). If the Banks A and B do not have accounts with the settlement members, the FX spot leg funds are credited/debited on their local central bank accounts later on the value day when the TARGET2 and Fedwire systems process the SWIFT MT202COV messages. These instructions need to be delivered to the local central bank systems before the CLS accounts become locked by the CLS system at around 06:00 CET for the settlement and funding process. In accordance with Mustish (2016), the settlement members fund their accounts upon receiving the final pay-in schedule. In accordance with Massarenti et al. (2013), the TARGET2 system processes the payment instruction with the finality for 5-30 min.

On the same step the CLS system locks the Banks X and Y’s CLS accounts at the ECB and the FED starting after 06:00CET in order to perform the settlement starting at 07:00 CET and pay-in/pay-out processes finalizing by 12:00CET. The PvP settlement applied in the CLS system ensures, that the trade settles only if each counterparty pays the agreed amount. The settlement members are paid back the submitted amount if their counterparty fails to pay by 12:00 CET. As soon as the transactions are settled in the CLS system the Banks X and Y become informed via the communication service between the CLS and the settlement member, so they can forward or transmit the details to their third parties.

As it is described above, the Banks X and Y take on the settlement risk on behalf of the Banks A and B during the settlement cycle in the CLS system (IMF, 2010). However, it should be pointed out that the Clients A and B are still exposed to the settlement risk, as they are debited with the corresponding leg funds later on the value day. The delay can be associated with several reasons. The first one is related to the fact that the Banks X and Y need to initiate the payment settlement via the CB network in order to credit the funds on the

Banks A and B accounts at the ECB and FED, if the last ones do not have the accounts with the Banks X and Y. The second reason is an unwillingness of the Banks A and B to credit the funds at the Clients' accounts as soon as these funds are received at their accounts with the Banks X and Y, or accounts at the ECB and FED due to limited liquidity. In accordance with the above facts it can be assumed the Banks A and B credit the funds to their Clients A and B' accounts at the early morning or only by the end of the value day (step 4).

Settlement risk duration and exposure

The average settlement lags for the simple cross-border payment and EUR/USD spot trade via the CLS system are listed in Table 3.2. As it can be seen from the results, the simple cross-border payment can be settled with the finality via the CLS system only on day (T+1) or on the next day from the day when the payment order is received by the Bank A. It is associated with the fact that the CLS system settles the payment instructions only between 07:00 and 12:00CET on business days in order to coincide the CLS settlement and funding cycle with the operating hours of the corresponding RTGS systems, and thereby, ensure the liquidity or settlement accounts for clearing and settlement.

There is no sense to investigate several cases when the Client A submits the payment (as it was done in Chapter 3.1), as it does not influence on its settlement risk duration and exposure. The *settlement risk duration of the Clients A and B* starts at 00:00 CET or at 06:30 CET which presents the latest times when the counterparties can amend or rescind the payment instructions on an unilateral basis and on a multilateral basis correspondingly on the settlement or value day. As it is commonly accepted to count the cut-off time for unilateral cancelation as initiation of the settlement risk (Tanai, 2008), 00:00 CET is considered in order to calculate the settlement risk duration for the Client A and B.

The settlement risk duration in case of the simple cross-border payment can be 14 or 22 hours depending on the behavior of the receiver Bank B. If the Bank B postpones crediting the fund transfer on the Client's B account until the end of the day (22:00CET), then the settlement risk duration is about 22 hours. The shortest settlement risk duration (14 hours) is achieved when the Bank B credits the fund on the Client's B account in the morning hours (assumed as at 14 CET) on the value day in the US. If the banks have limited liquidity at their account at the ECB and the FED, they may postpone the payments until the end of the day in order to avoid taking the intra loans and to cover the obligations by the incoming funds during the day.

In case of the FX spot trade the settlement risk duration is 14 hours or 16 hours for the Client A in Finland, and 14 hours or 22 hours for the Client B in the US. The longest settlement risk duration is associated with the cases where the Banks A and B delay to credit the net funds to the Clients A and B' accounts until the end of the value day due to limited liquidity, using only end of day confirmation and other reasons. The Client B may have 6 hours longer settlement risk duration than the Client A due to the longer operation hours of the Fedwire system in the US. The time zone difference plays against the counterparty in the later time zone in the FX spot contract.

The Banks A and B can credit the corresponding funds on the Clients A and B' accounts even earlier or at around 05:00-06:00CET if they receive the funds at their accounts at the Banks X and Y correspondingly. If the Banks A and B do not have the account with the Banks X and Y, then the funds are credited via the central systems (CB) and it takes more time. It should be said that the settlement risk duration can be even less (just 4 hours) if the Clients A and B could have the accounts at the Banks X and Y and, thereby, settle the cross-border payment and FX spot trade directly via the CLS direct members. In the assumed conditions the CB settlement increases the settlement duration by several hours.

The *settlement risk exposure of the Client A* is constant and equals to the payment nominal amount during the whole settlement process in the case of the simple cross-border payment. In case of the FX spot trade the *settlement risk exposure of the Clients A and B* fluctuates only after the settlement in the CLS. The PvP settlement ensures the settlement finality of both trade legs payment simultaneously, and thereby, it protects the Clients A and B against the principle risk during the CLS settlement. However, both Clients have two exposure periods (nominals of the bought and sold legs) at several hours (4-18 hours) during the settlement period via the CB.

The settlement exposure can be avoided for the Clients A and B if they settle the trade via their accounts with the CLS settlement members (Banks X and Y). The CLS settlement members have only the credit risk exposure of the net balance at their CLS account during the five-hour settlement and funding period in the CLS system. The settlement risk exposure duration of both Clients can be longer if they arrange the FX trade or cross-border payment in currencies other than their specific currency jurisdiction (CAD, JPY). In this case the Banks X and Y would need to contact their correspondents in these specific currency jurisdictions (Canada and Japan) in order to ensure the pay-in requirements in the relevant currencies.

Table 3.2: Settlement steps and its average duration in transactions via CLS

Source: Author's own calculation

Settlement step in cross-border payment and FX spot EUR-leg (*USD-leg*)	Cut-off time for outgoing/ incoming payment	Technical settlement delay	Settlement lifecycle of EUR/USD cross-border payment	EUR-leg of FX spot trade (Client A)	USD leg of FX spot trade (Client B)
Handling payment instructions in Banks A and B from Client A and B and sending SWIFTNet MT304 to Banks X and Y	16:00CET[1] (*13:00CET*[6]) -	90 min[6] (30 min[7]) 10 min	13:00CET on day T -> processed and sent at 14:40CET on day T	15CET at (V-2) -> processed and sent at 15:30CET on day (V-2)	15CET at (V-2) -> processed and sent at 15:30CET on day (V-2)
Handling payment instructions in Bank X and Y and sending MT304 to CLS Bank	- 06:30CET	30 min 10 min	14:40CET on day T -> 15:20CET on day T	15:30CET-> 16:00CET on day (V-2)	15:30CET-> 16:00CET on day (V-2)
Cut-off time for payment instruction amendment by Client A and B: - unilateral	00:00CET	-	**00:00CET at day (T+1)**	**00:00CET at day V**	**00:00CET at day V**
Handling IPIS in Banks X and Y and credit/debit the accounts of Banks A and B on own books or sending SWIFT MT202 to TARGET2 and Fedwire	06:00CET -	- 10 min	15:20CET on day T-> 04:00CET on day (T+1)	15:20CET -> 04:00CET on day V	15:20CET -> 04:00CET on day V
Handling fund transfer between Bank X (Bank Y) and Bank A (Bank B) via TARGET2 (Fedwire)	*07:00-18:00 CET*[3] (03:00-00:00 CET[4])	5-30 min	04:00CET->07:20CET on day (T+1)	04:00CET->07:20CET on day V	04:00CET->04:20CET on day V
Handling fund transfer between Bank X and Bank Y via CLS	12:00CET[7]	5 hours	07:00CET->12:00CET on day (T+1)	07:00CET->12:00CET on day V	07:00CET->12:00CET on day V
Handling payment to Client B (Client A) in the Bank B (Bank A)	22:15CET[5] (16:00CET[6])	120 min	1. 07:20CET -> **14:00CET on day (T+1)** 2. 07:20CET -> **22:00CET on day (T+1)**	1. 07:20CET -> **14:00CET on day V** 2. 12:30CET -> **16:00CET on day V**	1. 07:20CET -> **14:00CET on day V** 2. 12:30CET -> **22:00CET on day V**
Total settlement risk duration (exposure) for Client A and Client B	-	-	**1. 14 hours (N)** **2. 22 hours (N)**	**1. 14 hours (N)** **(N^A+N^B for 14 h)** **2. 16 hours (N)** **(N^A+N^B for 14 h)**	**1. 14 hours (N)** **(N^A+N^B for 14 h)** **2. 22 hours (N)** **(N^A+N^B for 14 h)**

[1]Nordea (2018); [2]CITI (2018); [3]ECB (2018); [4]FED(2018); [5]HSBC(2018); [6]Ulster Bank(2018); [6]Hoflich(2011), [7]CLS(2015)

There are several risks in the CLS platform for the settlement members. The first risk is associated with the fact that if the settlement in one of the currencies is not successful for the direct member, the pay-out in another currency can be locked. The second risk is related to liquidity shortage during the 5-hours settlement cycle in the CLS system, as the settlement members cannot use their funds during that time. The third limitation of the CLS system is a short settlement window and expensive intraday liquidity for the direct members in this period. The forth risk is associated with the significant liquidity pressure on the settlement members if one of them defaults on its obligations during the CLS settlement process. However, the fact that only direct partners of the central banks participate in the CLS settlement reduces adverse selection and moral hazard problems in the network.

3.3 Settlement risk of simple cross-border payment and FX trade via USC arrangement

The USC platform can be applied for peer-to-peer settlement of cross-border transactions and FX trades between the financial institutions in the participating countries. Fig. 3.5 and 3.6 illustrate the settlement schemes of the simple cross-border payment and FX spot trade correspondingly. The settlement delays within each step are shown in Table 3.

Simple high-value cross-border payment

In order to transfer a high-value cross-border transaction from Finland to the US, the Client A places a payment request and beneficiary details with the Bank A where he/she has an account. At the first step the Bank A confirms the payment details, books the specified amount in EUR at the Client A’s account and informs the receiver Bank B about the incoming funds. Although the payment handling and screening takes about 60-180 min in the traditional systems (Ulster Bank, 2018), it can be assumed that these processes can be limited to about 30 min in the DLT-based network by using the common dataset of customers, shareholders and the USC participants. However, it can be difficult to cut the handling and screening of high-value payment to seconds, as the regional regulatory requirements for customer onboarding and sharing of their personal data are diverse in different regions (McWaters, 2016). It means that the regulatory compliance checks can still be time-consuming in the DLT-based platform, as every party node should be compliant with the Bank Secrecy Act (BSA), transaction monitoring on AML, CFT and KYC, reporting of suspicious activity and other different regional requirements (Natarajan et al., 2017).

As the Banks A and B operate party nodes in the USC platform, they can settle the payment directly between each other. The USC platform can offer a bilateral channel for each pair of the party nodes in order to fulfill the privacy of fund transfers and customers private data. After the Bank A confirms the Client A's payment instruction, it signs the payment order digitally with a private key and forwards it to the USC platform for further settlement (step 2). The USC system operator transmits the payment instruction to the notary for several important security checks. The first of them is to authenticate the Bank A's private signature and payment details in order to ensure that the sender and beneficiary are claimed and legitimate financial organizations, and the transmitted payment data has not been manipulated (integrity of payment message). The second check is related to verifying that the sender has sufficient liquidity at its USC account in order allow the payment to be added to the ledger by the USC system later. In this way the notary node (the ECB) performs a validation role by eliminating double spending problem and authenticating the party digital signatures.

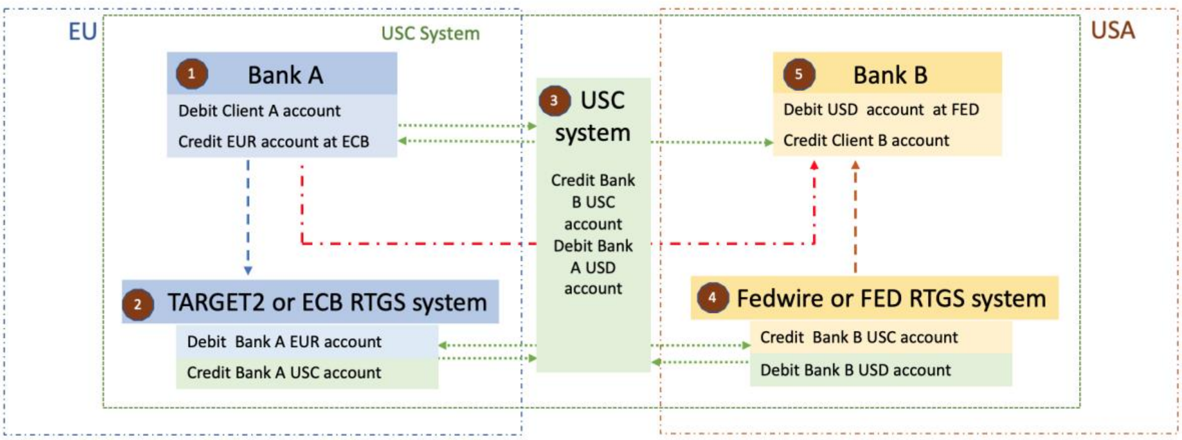


Figure 3.5: settlement of cross-border payment via USC system
Source: author's own illustration based on KPMG, 2018

The ECB reserves the specified funds at the Bank A's USC account in accordance with the payment instruction. If the Bank A does not have enough liquidity at its USC account, then the required USC is issued by the ECB based on the pledged EUR at the Bank'A collateral account. As soon as the transaction funding is confirmed, and the private digital signature is authenticated by the ECB, the payment instruction becomes accepted and signed with the public key for further settlement in the USC platform. The USC system maintains the consensus over the future settlement process updates. In accordance with Neto et al. (2017), the verification process in the notary node or central bank can take about 10 min.

At the third step, the USC system operator receives the transaction endorsed by the notary, packages it in the block, and broadcasts it to the party nodes for the final approval. As soon as the Banks A and B validate the transaction, the payment becomes committed to the ledger shared between the relevant parties – the Banks A and B, and their correspondent central banks. In this way the deterministic payment finality is applied in the settlement process, where the mining is restricted to one node (notary or USC operator), while the ledger with transaction details and balances is shared between the relevant party nodes and notaries. The time of the final approval by the party nodes can be assumed as the initiation of the settlement risk for the Clients A.

The ECB and the FED are responsible for transfer and receipt of the USC at the beginning and conclusion of the matching cycle in the USC platform. In this way the ECB debits USC at the Bank A's USC account on the request from the USC system before the matching process, and the FED credits the settlement proceeds to the Bank B's USC account on the confirmation from the USC system after the matching process (step 4). When the FED credits USC at the Bank B's USC account, the Bank B can collect them in the form of USD at its collateral account at the FED. In this way the USC can be redeemed by the FED. At the final step the Bank B credits the funds to the Client B' account in USD after verification and screening process of the incoming payment details. It can be assumed that the verification and screening process takes about 30 min.

FX spot trade

Fig. 3.6 illustrates the EUR/USD spot trade between the Client A in Finland and the Client B in the US. At the first step, the Clients A and B agree the EUR/USD spot deal on date T (or V-2) and request the Banks A and B to perform their payment obligations specified in the contract. As soon as the Banks A and B confirm the payment and beneficiary details, and perform the required regulatory compliance screening checks, they can place the transaction requests to the USC platform using their party nodes in order to settle the deal obligations of their customers. The settlement date of the FX spot contract is usually T+2 (or V), so the Banks A and B can transmit the payment details straight on the trade day or later on the value date to the USC platform.

When the USC system operator receives the payment orders signed digitally with the private keys of the party nodes (the Banks A and B), it validates the payment details and forwards them further to the notary nodes (the ECB and the FED) for the uniqueness and validation checks. It can be assumed that the USC transmits the payment orders almost simultaneously (in 1 min) if all the required payment details are in place. The corresponding central banks validate the party nodes' digital signatures, data attributes of the payment orders and the USC account statements of the Banks A and B before they provide approvals and sign the payments with the public keys (step 2). If the party nodes do not have enough means at their USC accounts to meet their obligations, the ECB and FED request them to pledge more collateral at their corresponding collateral accounts in order the notaries can issue equivalent amount of USC for the deal settlement. As described above, the settlement delay in the notary node can be assumed as 10 min (Neto et al., 2017; ECB and BJ, 2018).

At the third step the USC system operator gets the confirmed payments signed digitally by the ECB and FED, and it can start the matching cycle of the deal legs, as soon as the party nodes provide their final approvals. The times of the final approvals by the Banks A and B can be assumed as a start of the settlement risk exposure for the Clients A and B in the FX spot deal.

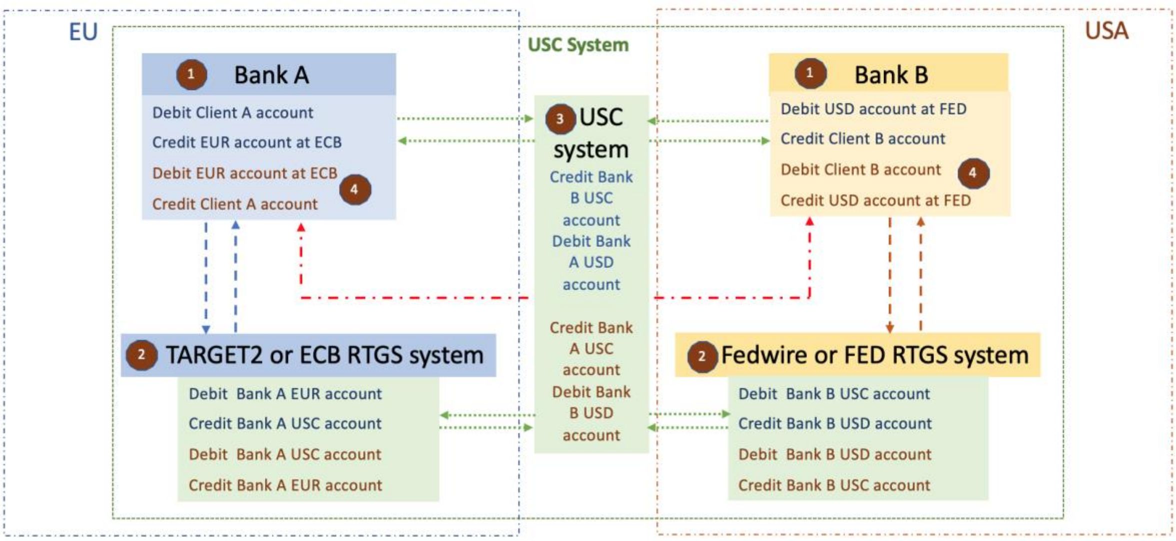


Figure 3.6: settlement of FX spot trade via USC system
Source: author's own illustration based on KPMG, 2018

In order to limit the liquidity needs of the party nodes, the USC platform can apply multilateral payments offsetting mechanism. It allows requesting just net settlement obligations from the Banks A and B, and the ECB and FED transfer (or receipt) only net amounts in USC for their account members during the matching cycle. When the Banks A and B get the matching confirmation and their USC accounts are updated with the deal proceeds, they can credit or debit the accounts of their Clients A and B correspondingly. As it was described above, the settlement delay can't be cut to seconds and minutes at the last step where the beneficiary Banks A and B should perform the time-consuming screening process of the incoming payment details in order to be compliant with the KYC, AML, CFT and other regional requirements (Natarajan et al., 2017).

Settlement risk duration and exposure

Table 3.3 lists the assumed settlement delays in each step of the payment process and settlement risk durations for the Clients A and B. As USC presents a universal fiat currency, and thereby, it eliminates many intermediaries within the clearing and settlement process (e.g. CB for foreign currencies), the minimum *settlement risk duration* can be limited to about 34 minutes in cases of the high-value cross-border payment from Finland to the US and the EUR/USD spot trade between the Clients from Finland and the US. However, it should be pointed out, that the analysis assumes the case where the Client submits the payment instructions before the cut-off time (16:00 CET) for outgoing payment in Finland and the payment reaches the beneficiary banks before its cut-off time (22:15 CET) for incoming payment. In order to have fast settlement risk duration for all players in different countries, it may be required to have 24/7 operational capabilities or support in the participating financial institutions and corresponding central banks. At the same time the smart contracts can help to limit the dependence of the USC platform on the operational availability of the notary nodes (e.g. TARGET2 and Fedwire) and the party nodes.

The settlement risk duration is initiated at the point when the transaction can't be canceled unilaterally (Tanai, 2008). In the USC platform the cut-off time for unilateral cancelation is a time when the party nodes (the Banks A and B) provide their final confirmations for the transactions endorsed by the notaries (the ECB and the FED). The analysis results in Table 3.3 demonstrate that the biggest contribution (about 30 min) to the settlement risk duration is associated with the beneficiary banks (Banks A and B). The initiator and beneficiary banks are obligated to perform the time-consuming screening process in order to meet the international and regional regulatory compliance requirements. This settlement delay is especially critical at the beneficiary end, as it is included in the settlement risk duration for the Clients A and B in cases of the high-value cross-border payment and FX spot trades.

The DLT arrangement is supposed to provide efficient, fully-automated and instant communication between the USC operator, party, and notary nodes operating on the USC platform. The USC system should ensure visibility of the shared ledger and updated transactional data to all need-to-know participants. In this view the confirmation processes between the USC platform participants should be fast and can be assumed as 1 min in most of the cases.

Table 3.3: Settlement steps and its average duration in transactions via USC system

Source: Author's own calculation

Settlement step in cross-border payment and FX spot EUR-leg (*USD-leg*)	Cut-off time for outgoing/ incoming payment	Technical settlement delay	Settlement lifecycle of EUR/USD cross-border payment	EUR-leg of FX spot trade (Client A)	USD leg of FX spot trade (Client B)
Handling payment instructions in Banks A and B from Client A and B and sending payment orders to USC platform	16:00CET[1] (*13:00CET*[3])	30 min	13:00CET on day T -> processed and sent at 13:30CET on day T	15CET at (V-2) -> 13:00CET on day V	15CET at (V-2) -> 13:00CET on day V
Handling payment instructions in USC platform and sending payment orders to USC platform to notary nodes	-	1 min	13:30CET -> 13:31CET on day T	13:00CET -> 13:01CET on day V	13:00CET -> 13:01CET on day V
Handling payment instructions in notary nodes – ECB and FED	-	10 min	13:31CET -> 13:41CET on day T	13:01CET -> 13:31CET on day V	13:01CET -> 13:31CET on day V
Final confirmation of signed payment order from Banks A and B	-	1 min	13:41CET -> **13:42CET on day T**	13:31CET -> **13:32CET on day V**	13:31CET -> **13:32CET on day V**
Matching of payments in USC platform and discharging of settlement proceeds from USC accounts of Banks A and B	-	5 min	13:42CET -> 13:47CET on day T	13:32CET -> 13:37CET on day V	13:32CET -> 13:37CET on day V
Handling fund transfer from Banks A and B' USC account to their EUR and USC accounts at ECB and FED	-	1 min	13:47CET -> 13:48CET on day T	13:37CET -> 13:38CET on day V	13:37CET -> 13:38CET on day V
Handling payment to Client B (Client A) in the Bank B (Bank A)	22:15CET[2] (16:00CET[3])	30 min	1. 13:48CET -> **14:18CET on day T** 2. 13:48CET -> **22:00CET on day T**	1. 13:38CET -> **14:08CET on day V** 2. 13:38CET -> **16:00CET on day V**	1. 13:38CET -> **14:08CET on day V** 2. 13:38CET -> **22:00CET on day V**
Total settlement risk duration (exposure) for Client A and Client B	-	-	**1. 36 min (N)** **2. 8h18min (N)**	**1. 36min** **(N^A+N^B for 36min)** **2. 2h28min** **(N^A+N^B for 2h28min)**	**1. 36min** **(N^A+N^B for 36min)** **2. 8h28min** **(N^A+N^B for 2h28min)**

[1]Nordea (2018); [2]HSBC(2018); [3]Ulster Bank(2018)

The longest settlement risk duration of the Clients A and B can be about 8 hours, and it is associated with the last steps in the settlement process in accordance with the above analysis. The payment counterparties are free of credit risk in the USC platform settlement, as USC is backed by the local currencies hold by the corresponding jurisdictions and the central banks are assumed free of credit risk. However, the Clients A and B are exposed to the credit risk and settlement delays in the Banks A and B, as they credit the funds at the accounts in the last step. In accordance with Galbiati and Soramäki (2015), the beneficiary banks may have an initiative to delay the settlement of the received payments until the last hours of the value date in case of the limited liquidity at their settlement accounts at the ECB and FED or in order to optimize their liquidity usage. Although these settlement delays increase the Clients risk, this behaviour of the banks is permitted as long as the funds are received on the same business day as agreed in the payment instructions.

3.4 Comparison of settlement solutions based on settlement risk duration, exposure, and costs

This part presents a comparison analysis of three settlement systems investigated in the previous parts 3.1-3.3. The settlement system should meet several important settlement principles and characteristics – exchange-of-value settlement, minimized operational risk, ensured confidentiality, clear settlement finality, the earliest settlement, higher number of settled transactions, less liquidity consumption, and lower costs (Leinonen, 2005).

Settlement risk duration and exposure

Table 3.4 summarizes the *settlement risk durations* for a simple cross-border high-value payment from Finland to the US, and the EUR/USD spot trade between the customers in Finland and in the US. The analysis results demonstrate that a DLT-based system allows limiting the settlement risk for the Clients A and B, as the cross-border transactions can be settled faster (in 0.5-2 hours) comparison to the traditional settlement systems based on the CB (5-24 hours) and the CLS system (14-22 hours). The main limiting factors for fast settlement in the traditional payment systems are many intermediaries with uncertain processes, enormous duplications, end-of-day accounts reconciliation due to costly SWIFT messages, and a short settlement window in the CLS system. The crucial factor is the costly liquidity offered by the central banks or liquidity providers. It creates incentives for initiator, correspondent, and beneficiary banks to delay the payments in order to wait for the incoming funds, and thereby, optimize their liquidity usage throughout the day. Another considerable factor amplifying the settlement risk duration is the regulatory compliance overburden. In the current payment arrangements, the initiator and the beneficiary banks spend several hours each in order to perform the necessary KYC, AML, and CTF checks and sanction screenings before the cross-border fund transfer can be sent or received by their clients.

Among the traditional settlement systems, the shortest settlement risk duration of the cross-border payment is achieved in the CB arrangements (5-9 hours instead of 14 hours in the CLS system). The main reason for this is a short settlement cycle (only in 07:00-09:00 CET) in the CLS system, and its inability to settle the cross-border transactions on the same day, when the payment instruction is received. The CB arrangements are more flexible concerning the settlement time, and thereby, they can offer a faster settlement and deliver the funds to the beneficiary on the same value day. However, the CB arrangement can be much slower in the unfavorable cases (e.g., manual errors, time zone difference, inconsistency in the payment message). The CLS system demonstrates its high efficiency in the settlement of FX spot trades, as it provides the synchronous settlement of the deal currency legs, and thereby, minimizes the settlement risk for both deal counterparties. However, in the analyzed case the non-direct participants of the CLS system expose their clients to a high settlement risk due to the CB parts in the settlement process.

Table 3.4: Settlement risk duration and exposure

Source: Author's own calculation

Settlement step in cross-border payment and FX spot EUR-leg (*USD-leg*)	cross-border high-value payment from Finland to the US	EUR-leg of FX spot trade between Client A in Finland and Client B in the US (Client A)	USD-leg of FX spot trade between Client A in Finland and Client B in the US (Client B)
Total settlement risk duration (exposure) for Client A and Client B in *corresponding banking arrangements*	5 - 12 hours (N)	9 - 24 hours (N) (N^A+N^B for 9-18 h)	4 – 18 hours (N^A+N^B for 4-18 h)
Total settlement risk duration (exposure) for Client A and Client B in *CLS system*	14 – 22 hours (N)	14 - 16 hours (N^A+N^B for 14 h)	14 - 22hours (N^A+N^B for 14 h)
Total settlement risk duration (exposure) for Client A and Client B in *USC system*	0.5 – 8 hours (N)	0.5 - 2 hours (N^A+N^B for 0.5-2 h)	0.5 – 8 hours (N^A+N^B for 0.5-2 h)

In accordance with the Eq.(1), the total *settlement risk exposure* of the cross-border transaction or FX trade is defined by the nominals of the initiated payment or the purchased currency, fluctuation of the applied currencies, service fee in order to initiate new payment (trade), and penalties associated with the failed or delayed main payment. The analysis results (Table 3.4) demonstrate that the nominals of the cross-border payment and FX spot trade (assumed as 500 000 000 EUR) are exposed to the settlement risk during the whole settlement risk duration in the studied settlement schemes. Although the CLS systems and the USC-system are supposed to eliminate the settlement risk in their settlement arrangements, the analysis assumes that the Clients A and B settle the trades via their banks or intermediaries and, therefore, the risk of non-delivery can't be eliminated in these conditions.

The hourly volatility of the EUR/USD exchange rate is 0.1-0.2 % where the highest hourly volatility is seen in the period between 08:00 CET to 16:00 CET in accordance with the forex market statistics (myfxbook, 2018). It means that the payer and the receiver of the high-value cross-border transactions are exposed to the significant liquidity costs and losses (500 000-1 000 000 EUR for the nominal of 500 000 000 EUR) in case of the fund transfer delay. The service fee in order to initiate a new transaction is probably not that large in the settlement systems, but the penalties from beneficiaries or counterparties can be significant in the wholesale payments.

The Eqs. (2)-(3) show that the netting applied in the settlement systems (RTGS, CLS) allows reducing significantly the FX settlement risk exposure, as the settlement parties are supposed to pay-in only 5-10% of their daily transaction turnover. However, as this analysis investigates the single payment and FX trade, it is difficult to assess how the netting effect can minimize the settlement risks of the Clients A and B.

It can be concluded, that the settlement based on the DLT network can benefit the customers with a shorter settlement time and, therefore, lower the settlement risk. The fully automated settlement systems with a shared authoritative ledger and end-to-end visibility allow better liquidity forecasting for corporates and financial institutions. The netting arrangements, limits on the party nodes' exposure, and application of collateral can help to mitigate the settlement risk in the USC platform. A broader access to the central bank settlement can be arranged using the USC settlement method, so the small financial institutions and corporate can avoid the settlement risk duration associated with the intermediaries. The analysis demonstrates that the biggest latency in the DLT-based settlement systems can be associated with the regulatory compliance checks, transaction verification, and its commitment to the ledger.

Settlement costs

The CB arrangement is expensive due to overfunding of Nostro accounts, enormous delays, and expensive credit lines for payments in other time zones. In accordance with McKinsey & Company (2016) and Norder (2018), the average cost of the international payment is about 30-60 EUR. However, in order to compete with the fintech startups, the payment cost should be about 2$ (McKinsey & Company, 2016). Table 3.5 lists the main costs drivers for the cross-border payments based on the investigation presented by McKinsey & Company (2016).

Table 3.5: Main cost drivers in international payments
Source: McKinsey&Company, 2016

	Traditional settlement systems	DLT-based settlement systems
Nostro/Vostro liquidity	34%	significant reduction
Claims and treasury operations	27%	significant reduction
Foreign exchange costs	15%	significant reduction
Compliance	13%	insignificant reduction
Payment operations	9%	significant reduction
Network management	2%	significant reduction

In accordance with Tasca (2016), it can be assumed that the settlement costs can be cut by at least 30% in the DLT-based system compared with the traditional payment systems. As the DLT-based system shares a single authoritative distributed ledger to all need-to-know parties, it should not be time-consuming and the manual processes associated with the accounts reconciliations, additional verifications, and auditing processes can be easily automated. The reporting costs can be limited as well, as the regulator can monitor all the transaction data via the shared ledger.

The highest cost of the participant in the USC platform can be a participant fee and collateral-quality assets in order to get the liquidity in USC. However, the marginal cost of additional on-ledger transaction should be low. The settlement of payments and trade cash legs in the USC can reduce the credit risk of the settlement parties, as the trades are settled intraday and in USC supported by collaterals in the central banks.

There are several costs of the traditional settlement systems which can be avoided in the DLT-based arrangements. The first of them is less tied-up collateral and liquidity in order to support the CB network. The shorter settlement cycle allows optimization of the liquidity usage by the financial institutions, and thereby, they can save on the liquidity costs. However, a crisis time can create liquidity pressure on the USC, as all financial institutions may prefer to keep their reserves in USC.

The second reduced cost is unfavorable exchange rates and haircuts applied by the correspondent, intermediaries, and the CLS system. As the CLS system is not protected against the settlement member defaults, the system issues the pay-in overall balance in accordance with the spot exchange rate plus a haircut on the settlement day. In the USC-based system the exchange rate can be more predictable and market-based.

The real-time overview of the transaction status is another benefit of the USC-based system. Although the direct participants of the CLS system are also constantly updated with the deal settlement status via CLS Web Access, their third parties can get the transaction statuses with some delays. It is crucially important for payer and receiver to be aware of the transaction status in international payments, as the late or failed transaction causes extra cost due to fines and unfavorable moves in the exchange rates on the markets.

The communication in the traditional payment systems is based mainly on the SWIFT messages. However, this communication network is expensive. In order to save the costs, many financial institutions tend to use the end-of-day statement message (SWIFT MT950) instead of real-time confirmations (SWIFT MT900/MT910) in the traditional settlement systems. This fact causes longer settlement time, and thereby, higher settlement risk, exposure, and costs for the payment payer and receiver. The communication in the USC settlement system can be centralized, fast, and cheap as more unified payment data and format standards can be introduced.

Security and reliability

The settlement of international payments supports safety and integrity for overall trade and financial systems in the world, so the financial institutions and regulators have high requirements to security and reliability of the settlement arrangements. The traditional settlement systems demonstrate acceptable reliability and security. However, many participants point out slowness, operational uncertainty, and low efficiency in the current settlement systems, so the CB settlement and the settlement based on the CLS can be difficult to compete with new payment providers.

The DLT-based settlement system has a potential to provide higher operational efficiency, and necessary security and reliability for trade and financial markets. The time-stamped and immutable shared ledger allows faster settlement and better overview of the settlement process. In order to assure the strict private data requirements, the special cryptographic solutions, such as zero-knowledge proof (Accenture, 2017), can be applied to validate the date without knowing all the details. The notary concept supports the fast settlement and immediate settlement finality.

In case of a liquidity shortage, the central banks or external liquidity providers can offer liquidity in the form of the intraday credit. The liquidity needs and costs can be minimized through special offsetting and payment prioritization mechanisms. The live monitoring and higher transparency of the transaction statuses allow the party nodes forecasting their liquidity needs more efficiently.

However, in the current state the DLT-based settlement systems do not have government and globally accepted legal frameworks in order to harmonize international services and interoperability. These critical issues compromise the development and testing of DLT-based solution the most for international payment settlement. The central banks, regulators, legal and technology experts need to collaborate more in order to agree on global standards for the DLT-based international payment system.

Several aspects have not been investigated in this analysis, but they can be crucial. The first of them is onboarding requirements for the participating financial institutions, corporates, Central Banks (RTGS systems) and the currencies under their jurisdictions in order to provide the trust necessary in the fund transfer operations. It is clear that many central banks and financial companies can not be included in an USC system due to their fair credit rating and unacceptable legal frameworks. The next aspect is alignment and harmonization of the technical and operational standards in the financial institutions and central banks around the world in order to settle the USC.

4. Concluding remarks

Cross-border wholesale payments are time-critical, and they require stable and reliable infrastructure in order to support efficient functioning of trade and financial systems. In the current state the international payment system presents a less robust, slow, and complex fund transfer arrangement with many intermediaries. The money transfer can take several days to be settled between two international banks today, as often these banks do not have reciprocal accounts or any trustable connections.

In this thesis I was aiming to investigate the settlement risk in three settlement arrangements of wholesale cross-border payments – the CB network, the CLS system, and the DLT-based system using USC. The approach presented by Tanai (2008) was applied in order to assess the settlement risk duration and exposure for a simple cross-border high-value payment from Finland to the US, and EUR/USD spot trade between the clients in Finland and the US.

The analysis results showed that the settlement arrangement based on the CB network is characterized by a significant settlement risk exposure, uncertain timing, slow and complex processes, tied-up funds, and endogenous costs. The efficiency of the CLS system can be easily compromised for the customers which do not have accounts with the direct settlement members, and thereby, become exposed to the CB drawbacks. To sum up, the settlement, operational, and credit risks in the traditional payment system had led to the current international settlement system based on tired participant model, where only a limited number of participants have direct access, and thereby, a low settlement risk exposure. It creates additional risks for lower-tier parties, as they are exposed to utilize the services of direct participants whose offering can be non-competitive and costly.

The DLT-based solution can offer more competitive payment infrastructure where the application of the USC allows achieving higher trust between the system participants thanks to the shared authoritative ledger. The analysis results show that the DLT platform can reduce the settlement risk duration to 0.5-8 hours compared with 5-24 hours seen in the traditional settlement arrangements. The faster settlement leads to a lower settlement risk exposure, less tied-up liquidity, and better liquidity forecasting for the settlement parties in the high-value cross-border transactions and FX trades. This efficient, robust, transparent, and resilient settlement arrangement is essential and vital for financial stability and economic development. However, it should be pointed out that the indirect participants of the DLT-based settlement system can still be exposed to settlement delays associated with time-consuming regulatory compliance checks, screening processes, and uncertain behavior of the direct participants targeting to optimize their liquidity usage.

The outcomes presented in this thesis can be used by corporates, financial institutions, and regulators in order to assess considerable settlement risk and exposure in the traditional payment system, and to proceed with the implementation of legal, operational, and cross-jurisdictional government frameworks for a future DLT-based settlement system. However, several limitations of this study should be pointed out. The first of them is associated with the chosen settlement schemes: the on-us and bilateral settlement arrangements are not included in this investigation. The second limitation is related to the applied approach to assess the settlement risk. This approach does not include the costs associated with the operational delays and the benefits related to the netting. As the third limitation, the chosen countries and currencies can be mentioned. The US and Finland (and correspondingly USD and EUR) present developed and low credit risk countries, whose payment systems are included in the CLS system and contain a good corresponding banking offering. The developing and high credit risk countries are exposed to a higher settlement risk in the view of sanctions and the regulatory compliance burden. The forth limitation is associated with the limited data resources and unwillingness of the banks to share their presumably competitive information in open access. This thesis is written based on the publicly available resources, so some details and system particulars can be missing.

The stated above limitations arise new topics for the further research. It can be interesting to investigate the settlement risk for the wholesale payment or FX trade between Russia and the US, Philippines and France, or Zimbabwe and Japan. Another possible topic can be the analysis of costs associated with the delayed and failed payments. As these costs are difficult to find in the published resources, a survey-based analysis can be applied.

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