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The Mexican Experience in How the Settlement of Large Payments is Performed in the Presence of a High Volume of Small Payments*

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Abstract: Payment systems play a key role in the financial infrastructure of all modern economies. Participants of payment systems need access to intraday liquidity to fulfill their payment obligations. They do that either using their own funds, which are costly, or recycling incoming payment. In order to rely on incoming payments, banks could delay the settlement of their own payment obligations. From the regulators' point of view it is important to know to what degree participants rely on the payments they receive from others. In Mexico, this is among the first studies that analyze from this perspective the intraday liquidity management of the Real Time Settlement Payment System, SPEI. We examine a data set of transactions from April 7 to May 7, 2010 in order to get insights of the participants' behavior regarding the delay of sending payment orders.
Keywords: Payment systems, intraday liquidity management, simulation.
JEL Classification: C63, G20, G28.

Resumen: Los sistemas de pago juegan un papel clave en la infraestructura financiera de todas las economías modernas. Los participantes de los sistemas de pago necesitan tener acceso a la liquidez intradía para cumplir con sus obligaciones de pago. Ellos realizan esto, ya sea con fondos propios, que son costosos, o reciclando pagos entrantes. Con el fin de reutilizar los pagos entrantes, los bancos podrían retrasar el envío de sus propias obligaciones de pago. Desde el punto de vista de los reguladores es importante saber hasta qué grado los participantes reutilizan pagos recibido de los demás. En México, este es uno de los primeros estudios que analizan desde esta perspectiva la gestión de la liquidez intradía realizada en el Sistema de Pagos de Liquidación en Tiempo Real, SPEI. Examinamos un conjunto de transacciones de 7 abril al 7 mayo 2010 con el fin de obtener una perspectiva del comportamiento de los participantes en términos de la demora del envío de órdenes de pago.
Palabras Clave: Sistemas de pago, gestión de liquidez intradía, simulación.

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1. Introduction

Payment systems have evolved over time as modern economies are becoming more and more dependent on the services they provide. Their key role in the financial infrastructure is changing from being used to discharge large financial market payment obligations, to becoming an important service provider not only for all kinds of businesses, but also for individuals. The technological innovation and the increased awareness of cost savings from electronic payments are among the main drivers for changes in the payment service industry. Ongoing innovation is likely to diversify even more payment types competing on the consumer service level, whereas efficiency and cost reduction could be the main reasons for integration of payments processing and settlement. The development of those processes with opposite directions, diversification and integration, differ across countries. For instance, in the European Union, despite specific country requirements and payment services preferences, the need for international integration has driven the creation of two payment platforms - the cross border financial infrastructure, the Single Euro Payments Area (SEPA) and the Large Value Payment System (LVPS) TARGET2, which nowadays are among the most advanced examples of standardization and process integrations [14].

In this context, it is worth it to highlight the fact that the volume of direct credit transactions has experienced important growth in the last few years. In Canada, for instance, the volume of direct credit transactions rose from 857.3 million in 2005 to 1,201 million in 2010, overcoming the annual volume of check transactions since 2009 and nowadays is the second instrument in terms of relative importance, after payment cards, according to [8, 9]. In another example, in the Euro area the use of credit transactions is also growing, even though this payment method there is the third in relative importance. It rose from 12,391 million reported for 2001 to 16,187 million reported form 2010 according to [11]. In Mexico, even though on a different scale in the volume, electronic retail payments have grown significantly. In 2002 there were 884 million non-cash transactions including checks, card payments (credit and debit cards) and electronic transactions (direct credit and direct debit), whereas in 2010 the number rose 1.6 times to 2,300 million transactions[1].

This tendency could have two possible consequences, which need to be considered. The first is the growing demand for urgent small payments and the second is the increased aggregated value of the transactions, which with time could become systemically important. Adding to those two factors the necessity of cost reduction, it could be that in the near future, real time high-value payments and low value electronic payments may be settled together. To achieve this, due to the volume of transactions settlement engines need to ensure highly efficient liquidity usage with the guarantee that retail payments do not delay time sensitive payments that settle important financial market obligations. In this line of research, mainly the efficient use of liquidity, several studies have been developed in the last decades among which are [3, 7, 10]. To that end, payment systems need to establish timely and liquidity–efficient operational rules, which

[1] Source: Central Bank of Mexico

will allow the settlement of a high volume of retail payments with minimum pressure on intraday liquidity usage. This issue has become in the last decade a central bank policy concern, not only because central banks usually are operators of the LVPS, but also from the perspective of the regulator [4, 13, 15, 16].

SIX Interbank Clearing SIC (the Swiss Interbank Clearing System), with volume of 394.7 million transactions reported for 2010, is the best known example of a LVPS that processes retail payments [9]. Also, other countries like the Czech Republic, Serbia, Slovakia, Turkey, Ukraine and Mexico use one system to settle wholesale payments and low value payments together [2]. In Mexico, a significant number of low value direct credit transactions between banks goes through a Real Time Settlement Payment System, SPEI, together with the settlement of large value payments. The system is operated by the Mexican Central Bank and it settles payment orders in real time, charging its participants a 0.50MXN per payment. In 2010 it processed 80.1 percent of the volume of the Large Value Payments in the country, according to [9]. SPEI processes, on average, around 500,000 operations daily. More than 80% of the transactions are payments with value lower than 100,000 MXN and, only 1.3% of the transactions are above 10,000,000 MXN.

One of the most important advantages in using real-time gross settlement (RTGS) systems for settling Large Value payments is the elimination of settlement and credit risk that could arise between participants (further referred to also as banks) in deferred net settlement systems [5]. Nevertheless, as a consequence, RTGS systems require relatively large amounts of intraday liquidity to support payment obligations, in comparison with deferred net settlement systems. This liquidity can be sourced from the participant's funds, usually in the form of intraday overdrafts obtained from the RTGS operator (the central bank) or from incoming payments from other participants. In that way, by delaying payments the banks' behavior determines the underling structure of the payment instructions' settlement.

In the present study our interest is focused on participants' decisions to delay payment orders, with the assumption that individual liquidity usage is determined by the size and urgency of the payment transactions [20]. Nevertheless if urgency is not strictly demanded, the delay in the settlement of payment orders could reduce the level of individual liquidity usage. Here, it is important to clarify that if banks do not know in advance the size and the time of incoming payments (which is our assumption), the delay of payments could be a signal that the participant would like to rely on the incoming payments to settle her own obligations [5, 12, 19]. However, given the complex interdependence game among banks and the operational rules in place in the particular payment systems, delaying payment orders does not necessarily imply less liquidity usage per participant. Furthermore an unbalanced interdependency among banks could raise concerns about the level of settlement risk triggered by individual behavior, which eventually could turn out to have systemic consequences. In this context operational rules could play a crucial role to avoid having participants depend excessively on incoming payments for settling their own obligations. Nevertheless before a proper framework to evaluate the participants' behavior is established, we believe that better understanding of the banks' intraday liquidity management is required and in particular we are interested in ascertaining which factors are taken into account in the delay of payments.

To that end, in the present paper, in order to get further insights on the motivation behind participants' decisions to delay payments, we analyze a set of SPEI payment orders. Continuing with the line of study presented in [1], in which the authors analyze intraday liquidity management from a more general perspective, here our aim is to study how the delay of settling payment obligations is related to the different size and volume of the transactions. In particular given that SPEI settles together wholesale and retail payments, we have the opportunity to evaluate the payment delay , when settling in real time a large number of low-value payment transactions. We use payment transactions from April 7 to May 7, 2010 sent to SPEI from 9:00 a.m. to 17:00 p.m. The data for each payment transaction includes payer, payee, transaction amount, time of reception and time of settlement. The currency used is Mexican Pesos MXN[2]. For our analysis, we perform two case studies. The first is an empirical study and is presented in two parts. The second is performed in a simulation environment. The rest of the paper is organized as follows: in the next section we briefly present the notation used for our study. Following that, in section 4 are the results obtained in the first part of our empirical study. Afterwards in section 5 we present the second part of the empirical study and in section 6 the results obtained from the simulation study. Finally, in section 7 we conclude with our mayor findings and suggestions for future research.

2. Structure and Notation

In this section we describe the variables used to measure the settlement delay. For each case study we measure the delay differently, but before we explain how we do that, let us start with a brief explanation of how the study is organized together with some of the operational rules of SPEI.

For the empirical study we divide the transactional data into four subsets, according to the value of the payment orders. The first subset contains the

[2] 1MXN = 0.076USD or 1MXN = 0.057EUR according to www.xe.com on 26 of April 2012.

transactions with value lower than 100 MXN[3]. The second subset includes payments with value between 100 and 1,000 and the transactions with value equal to 100. The third subset contains payment requests with value between 1,000 and 10,000 and transactions with value equal to 1,000. Finally, the fourth subset includes payment orders with value higher than or equal to 10,000.

In the first part of this study we evaluate the impact of the payments delayed on the level of intraday liquidity usage. We start by showing the general picture of the transactional data; i.e., on a daily basis we present for each subset of payment instructions a histogram of transactions, a time structure of all payments and a time structure of delayed payments. This includes the average time of delay per payment, the aggregated time of delay, the average amount per transaction and the aggregated level of value of payment orders. In the second part of the empirical study we focused more specifically on the delayed payments. For each subset of transaction previously defined, we calculate the daily average time of delay, the daily proportion of payment instructions delayed and the daily average amount of transactions. In order to determine the difference among the four subsets, we compare the statistical measures obtained.

In the second case study, in order to evaluate the overall impact of the postponed payments, we define a specific measure[4] $\mathcal{V}$, which represents on the aggregated level millions of MXN per minute delayed. For that reason we divide the data into four subsets, but this time in the following way. The first subset contains all payments, the second includes transactions with values higher than or equal to 100 MXN, the third contains payment orders with value higher than or equal to 1,000 MXN and finally the fourth subset includes transactions with value higher than or equal to 10,000 MXN. In a simulation-based environment reproducing the operational conditions of SPEI, we process each subset of transactions separately. We then make a comparison between the first set (all payments) with each one of the rest of the subsets. In order to compare the calculated delay $\mathcal{V}$ more accurately, we always consider for our analysis the same set of transactions. Thus from the first subset (all payments) only those higher value payments, which are included in the compared subset are present in the benchmark value. In other words, for the set of all payments, we calculate $\mathcal{V}$ three times - for the transactions with value higher than 100 MXN, for the payment orders with value higher than 1000 and finally for the payment instructions with value higher than 10000. We compare the specific $\mathcal{V}$ obtained for each subset with the $\mathcal{V}$ corresponding of the first subset.

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[3] From now on all references to the value of the payment transactions are in thousands, at least, unless stated otherwise.
[4] For details of how we calculate the delay in millions of MXN per minute, see equation (1).

Regarding the operational rules of SPEI, the system receives payment instructions continuously during the day, which are placed in a queue. It closes operations at 17:35 and starts processing payments for the next working day at 19:00. During operation time, a settlement process (SP) is executed at the latest 20 seconds after receiving a new payment. Payment instructions, which are not settled in a certain SP are kept in the queue and are considered for settlement in the subsequent processes. After execution of the latest SP before the operation is closed, payments in the queue are cancelled.

The intraday liquidity needed to support payment obligations, can be sourced from the participant's funds, usually in the form of intraday overdrafts obtained from the RTGS operator (the central bank) or from incoming payments from other participants. The latter allows banks to recycle liquidity in order to offset outgoing payment instructions [6, 17, 20]. That way the liquidity cost of making payments is reduced, as participants avoid incurring overdrafts from the central bank, which requires pledging collateral or maintaining high quality securities (government debt) for repos. In other words, the amount of liquidity used depends among other factors on the time of sending payment orders and on the particular sequence and size of the transactions, which are strategic decisions by the participants (for more detailed analysis of the factors determining the liquidity usage see 19). In that way, in order to efficiently use the different sources of liquidity, the intraday liquidity management consists of a careful scheduling of the settlement of payment orders throughout the day [5].

Nevertheless the information revealed from the transactional data we use does not reflect for how long the payments sent to SPEI have been at the participants' own queue. We can only observe from the data the difference between the reception and settlement time of each payment. According to the operational rule of SPEI, the reason why a payment is not settled in the next SP after reception is because either funds are not available in the sender's account to cover, or there are no incoming payments to offset the payment request.

In order to measure the settlement delay, let $\mathcal{P}$ be the set of payments received and processed by SPEI in one day and I be the set of participants in SPEI such that $p_{i,j}$ is a payment in $\mathcal{P}$ from the participant $i \in I$ to participant $j \in I$; $t_{p_{i,j}}$ is the sum of minutes passed from the first SP launched immediately after the reception of the payment instruction $p_{i,j}$, until its settlement[5]; $\varphi_{p_{i,j}}$ is the amount in MXN of $p_{i,j}$. The settlement process is performed either every 20 seconds or after the reception of 300 payments, whichever happens earlier. For the propose of our analysis, we consider that regardless of the reason, the payment is delayed if

[5] Note that $t_{p_{i,j}}$ could represent a fraction of a minute.

$t_{p_{i,j}} > 1\,min$, which means that there were at least three or more settlement processes before the payment finally was settled.

In our second study case, the aggregated delay $\mathcal{V}$ of settlement during one day, measured in terms of billions of Mexican pesos in one minute, is defined in the following way:

$$\mathcal{V} = \sum_{p_{i,j} \in \mathcal{P}} \left(t_{p_{i,j}} \varphi_{p_{i,j}} \right) \tag{1}$$

It is worth highlighting that if the funds of the participants are sufficient to settle every $p_{i,j} \in \mathcal{P}$ in the next SP launched immediately after the reception $p_{i,j}$ then $\mathcal{V}$ =0.

In order to perform this test we need to define the minimum required level of intraday liquidity. In Large Value Payment Systems, the term intraday liquidity is used to define the funds that the participants have to cover their payment obligations during one day. Those funds come primary from two sources: firstly participants' resources from previous balances or electronic transactions from other payment systems and secondly from payments received during the day from the rest of the participants. For our study, we establish the minimum required level of liquidity in terms of participants' resources. To that end, we have defined several measures listed in what follows. First, for each $i \in I$ the intraday payment orders sent are defined as:

$$p_i^{snt} = \sum_{j \in I} \varphi_{p_{i,j}} \tag{2}$$

whereas the received payments are denoted as:

$$p_i^{rcv} = \sum_{j \in I} \varphi_{p_{j,i}} \tag{3}$$

We define ℓ_i^{min} as the lower required level of liquidity for settlement during the day per participant, which is determined as follows:

$$\ell_i^{min} = max\{(p_i^{snt} - p_i^{rcv}), 0\} \tag{4}$$

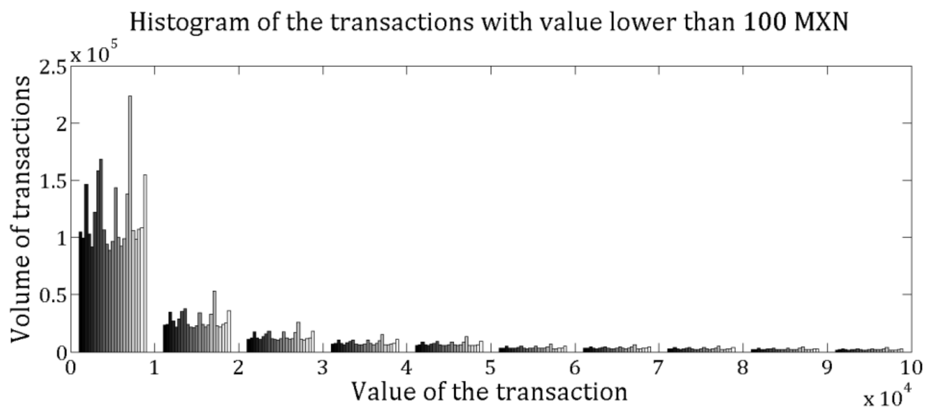
3. How volume and value is related to the delay of payments

In this section we present the histogram and the time structure of the volume of transactions for each subset previously defined as well as the corresponding time structure of the delayed payments. With the aim of distinguishing specific characteristics of banks' strategies related to the way participants are sending payment requests to SPEI, in what follows we list the behavior patterns observed for each subset of payments.

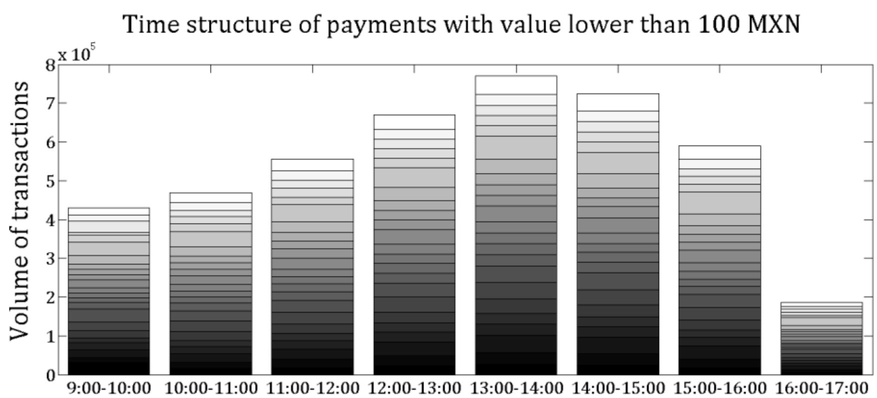
Table 1. Number of transactions per subset

Calendar day	Week day	Lower than 100	Between 100 and 1000	Between 1000 and 10000	Higher than 10000
07.04.2010	Wednesday	155,105	22,028	4,980	2,136
08.04.2010	Thursday	152,486	23,330	5,245	2,318
09.04.2010	Friday	224,792	30,200	5,951	2,608
12.04.2010	Monday	157,765	22,302	5,798	2,758
13.04.2010	Tuesday	137,454	21,011	5,563	2,577
14.04.2010	Wednesday	182,802	25,552	5,897	2,322
15.04.2010	Thursday	230,521	27,196	5,955	2,526
16.04.2010	Friday	250,805	31,548	6,255	2,621
19.04.2010	Monday	156,275	24,359	6,382	2,981
20.04.2010	Tuesday	139,684	19,808	4,805	2,999
21.04.2010	Wednesday	134,356	20,428	4,831	2,633
22.04.2010	Thursday	145,622	22,934	5,826	3,215
23.04.2010	Friday	220,872	30,596	6,069	2,792
26.04.2010	Monday	151,798	22,890	5,699	3,061
27.04.2010	Tuesday	138,812	21,867	5,375	2,645
28.04.2010	Wednesday	149,549	24,625	5,870	2,692
29.04.2010	Thursday	210,685	30,810	6,802	3,572
30.04.2010	Friday	340,610	42,498	8,830	4,023
03.05.2010	Monday	151,932	20,546	5,794	2,807
04.05.2010	Tuesday	142,973	19,613	5,129	2,823
05.05.2010	Wednesday	164,877	27,077	7,009	2,836
06.05.2010	Thursday	162,148	22,994	5,659	3,047
07.05.2010	Friday	233,578	29,760	6,417	3,665

For this analysis we have organized the data according to the value of the transactions, as previously defined: the first subset contains the transactions with value lower than 100 MXN, the second subset includes payments with value between 100 and 1,000 and the transactions with value equal to 100, the third subset contains payment requests with value between 1,000 and 10,000 and transactions with value equal to 1,000, and finally the fourth subset includes payment orders with value higher than or equal to 10,000. In all figures in this and in the next sections the studied period is presented with 23 different gray tones used for each day. We have used the same color representing the same day in all figures, starting with April 7, 2010(Wednesday) and ending with May 7, 2010 (Friday). The size of the transactions subsets per day are presented in table 1.

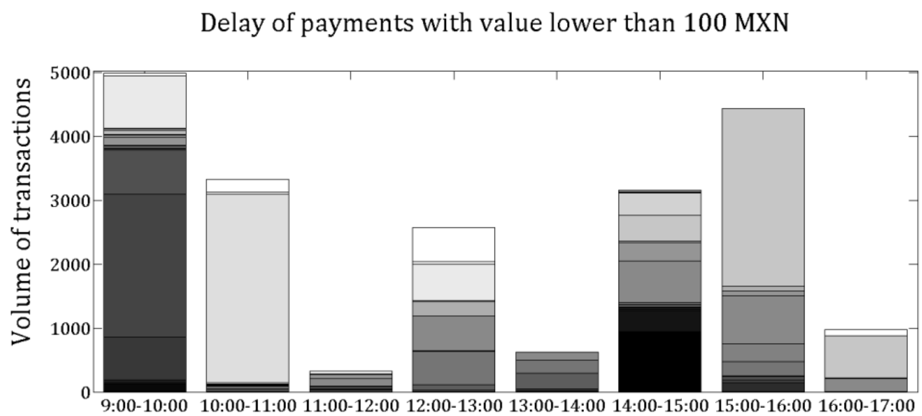


(a[6])



(b)

[6] In all figures the value of payment transactions are presented in thousands of MXN.



(c)

Figure 1. The case of transactions with value lower than 100 MXN

In figure 1 we present the subfigures elaborated with transactions having values lower than 100 MXN. In particular in subfigure (a) the histogram of the number of payment instructions is shown, in subfigure (b) we present the time structure of the transactions on an aggregated level and in subfigure (c) in the same way the time structure of the number of payments delayed is presented.

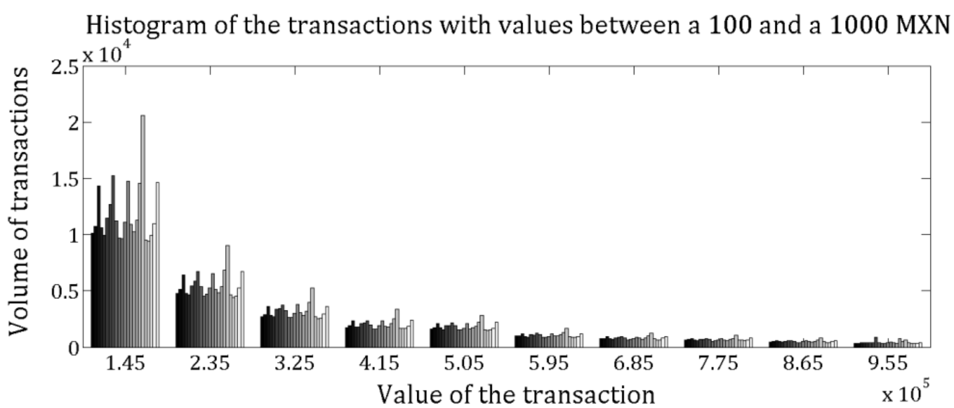
We observe in subfigure 1(a) that under normal operational conditions there are certain patterns in the way participants sent payment orders with value lower than 100. In particular, given the average and standard deviation calculated per day of the week presented in the first two rows in table 3, we can say that there is a weekly periodicity in such a way that Fridays the transaction volume is higher than the rest of the week, whereas Tuesday is the day with lower volume[7]. In comparison with the daily average and standard deviation presented in table 3, the weekday average calculated for Monday, Tuesday and Wednesday is lower than the overall daily average presented in table 3, whereas the standard deviation observed for each of the days of the week presented in table 2 is smaller than the standard deviation reported in table 3. Furthermore, Monday and Wednesday present the same average. In addition, the peak in terms of transaction volume observed in subfigure 1(a) corresponds to the last working day of the month, which is considerably higher than the rest. Finally we notice that the volume of low value transactions presented in the first decile of the histogram is above 100,000 transactions daily, which is significantly higher than the rest of the histogram's deciles.

[7] The 23 days of our simple includes 4 weeks and 3 days, starting on Wednesday and ending on Friday. The last working day of the month is Friday in the penultimate week of our sample.

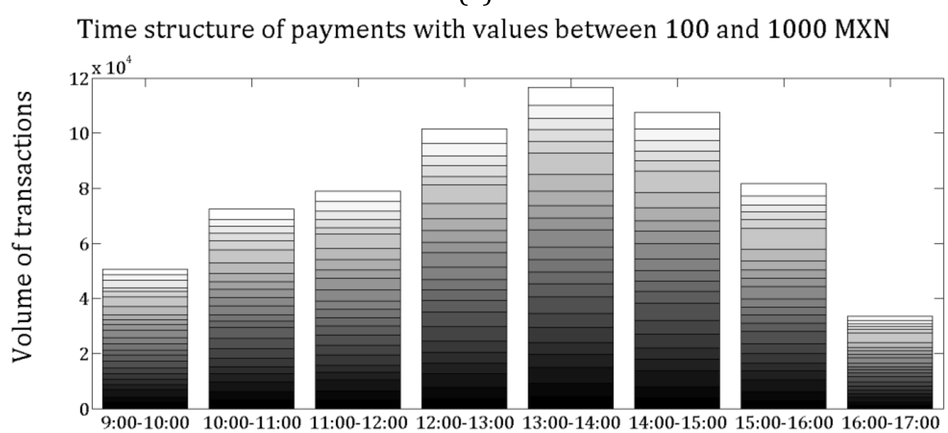
Table 2. Week day average and standard deviation per subset

		Monday	Tuesday	Wednesday	Thursday	Friday
<100	Avg	**166,164**	**150,471**	**166,134**	**192,061**	**267,119**
	Std Dev	*2,691*	*2,063*	*15,789*	*34,316*	*46,366*
100 - 1000	Avg	**25,426**	**23,336**	**25,179**	**28,388**	**36,151**
	Std Dev	*1,447*	*796*	*2,154*	*3,339*	*5,218*
1000 - 10000	Avg	**5,931**	**5,218**	**5,307**	**5,897**	**6,704**
	Std Dev	*266*	*284*	*474*	*512*	*1,075*
>10000	Avg	**2,902**	**2,761**	**2,385**	**2,936**	**3,142**
	Std Dev	*124*	*164*	*237*	*457*	*588*

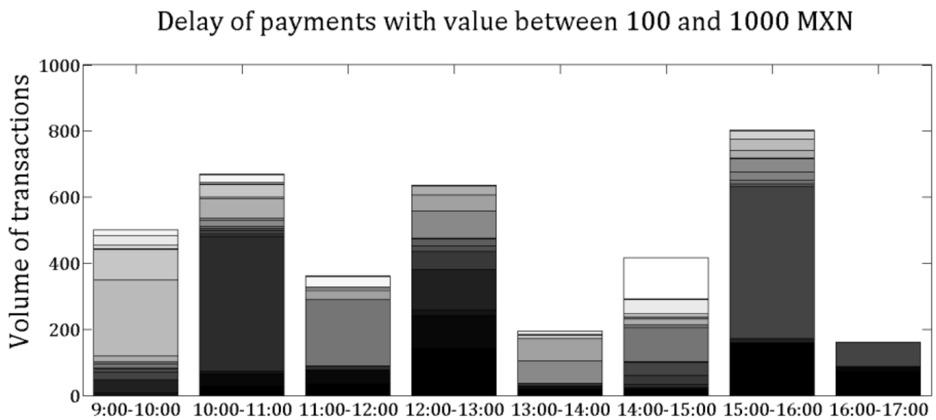
With respect to the time structure of payments with value below 100 presented in subfigure 1(b), a different regularity is observed. The volume of low value payments reported per hour is considerable throughout the day. The hour with the highest volume of transactions is between 13:00 and 14:00, followed by the transactions sent between 14:00 and 15:00. This observation could be an indication that participants prefer to send low value payments during the afternoon hours.



(a)



(b)



(c)

Figure 2. The case of the transactions with value between 100 and 1000 MXN

Regarding the time structure of the payments delayed shown in subfigure 1(c), regularity on a daily basis is not observed. We also notice that on certain days the number of delayed payments is significantly higher than others. According to the total and hour correlation coefficient between the number of transactions and the number of payments delayed presented in table 4, we can say that for this subset of transactions the hour with the highest number of payments delayed is between 15:00-16:00 and 16:00-17:00 followed by 9:00 and 10:00, whereas a negative correlation is observed for the hours between 10:00-11:00 and between 13:00 and 14:00. Finally we observe in subfigure 1(b) that the highest volume of payment transactions is between 13:00 and 14:00.

Next, let us look at Figure 2, in which the transactions with value between 100 and 1000 MXN are presented. In particular, as in the previous case in subfigure 2(a) the histogram of the number of payment orders is shown. In this subfigure a similar weekly regularity is observed, which is consistent with the weekday average and standard deviation presented in table 2, in which Tuesday is the day with the lowest level of transactions and Friday the day with the highest. Furthermore, Monday and Wednesday again have the same average as listed in table 2. Nevertheless, for this subset the difference among deciles is not that strongly underlined as in the histogram of the lowest payments.

Table 3. Daily average and standard deviation per subset

	Daily Average	Standard Deviation
< 100	**191,004.87**	*50,662.94*
100 -1000	**27,984.43**	*5,564.87*
1000 -10000	**5,832.22**	*822.53*
> 10000	**2,824.57**	*456.43*

Regarding the time structure of the payment transactions presented in subfigure 2(b), a regularity per hour is clearly observed, with the highest volume of transactions reported at 13:00-14:00 and then at 14:00-15:00. We notice that in comparison with subfigure 1(b), here the volume observed between 9:00 and 11:00 is lower than the volume of transactions from the rest of the day before 16:00.

Table 4. Coefficient of correlation between number of delayed payments and total transactions per subset

	< 100	100 - 1000	1000 - 10000	> 10000
Total	0.183	0.171	0.114	**0.639**
9:00 - 10:00	0.314	0.039	0.107	0.741
10:00 - 11:00	*-0.040*	*-0.092*	*-0.110*	0.705
11:00 - 12:00	0.231	0.280	0.369	0.739
12:00 - 13:00	0.046	0.016	0.045	0.332
13:00 - 14:00	*-0.090*	*-0.090*	*-0.002*	0.303
14:00 - 15:00	0.198	0.037	-0.109	0.118
15:00 - 16:00	0.775	0.838	0.675	0.790
16:00 - 17:00	0.828	0.778	0.874	0.623

With respect to the hourly structure of the delayed payments shown in subfigure 2(c), we observe that across days and hours the number of delayed payments varies. We focus our analysis on the hours before 16:00 and notice that between 15:00 and 16:00 is the hour with the largest number of payment delays, and the hour which also presents the highest correlation coefficient listed in table 4. In that table, for this subset of transactions a negative correlation is observed again between 10:00 and 11:00 and between 13:00 and 14:00. In addition, in this case the highest volume of payment orders observed in subfigure 2(b) is between 13:00 and 14:00.

In figure 3 we present the subfigures corresponding to the subset of transactions with value between 1,000 and 10,000 MXN. In this case the picture observed changes with comparison to the previous two figures. According to the data presented in table 2, the differences among the weekday averages is not that substantial, with the exception of Fridays, in which the highest volume of transactions is reported.

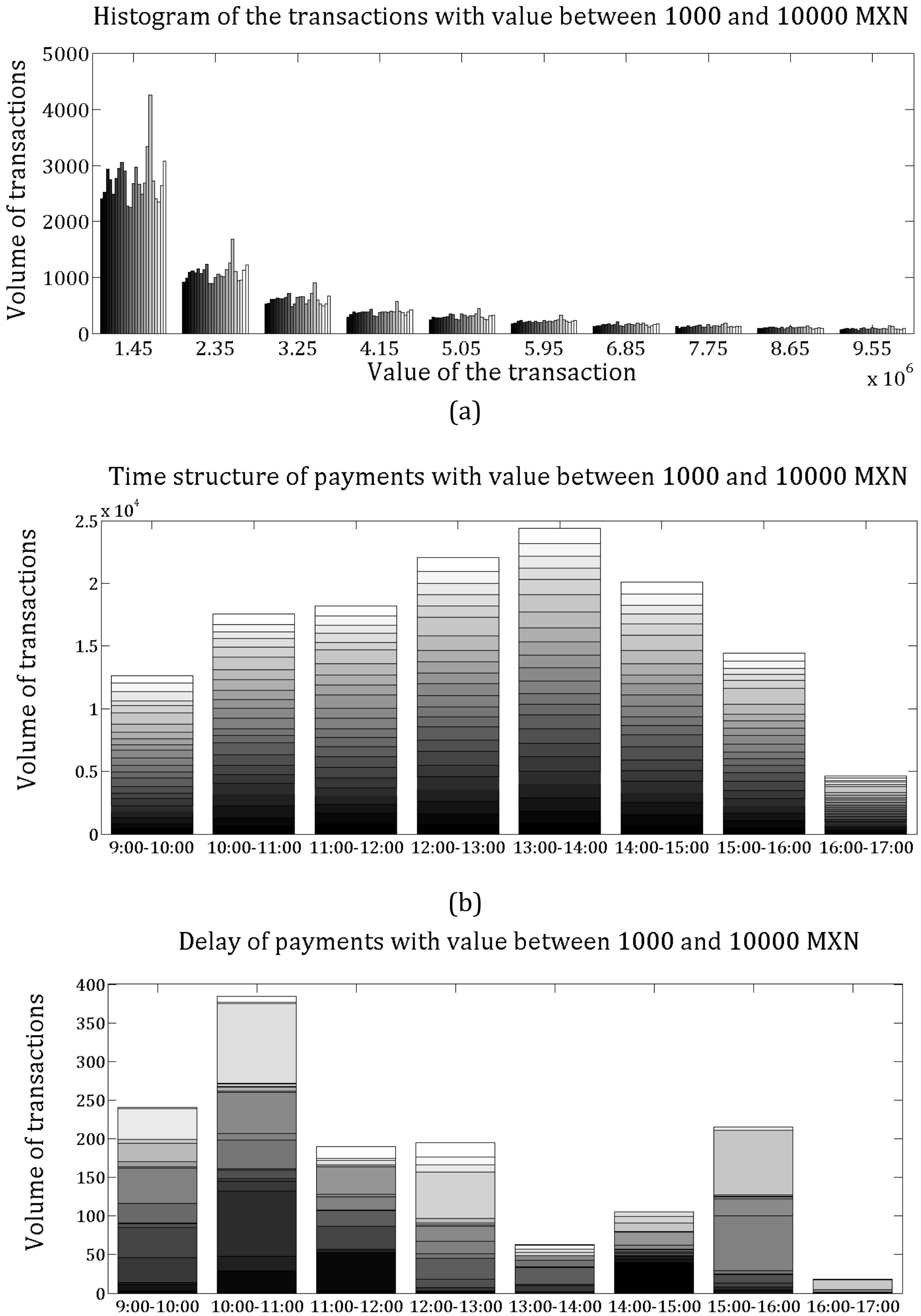
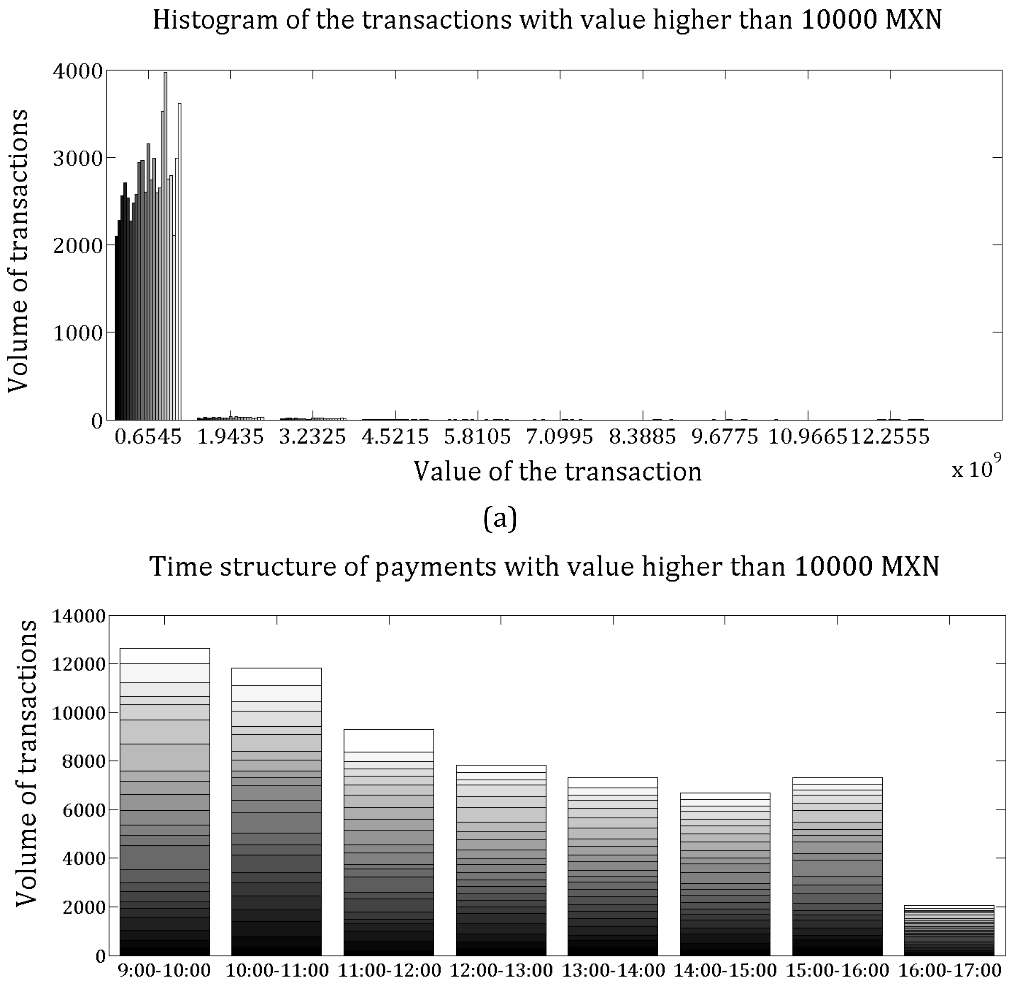


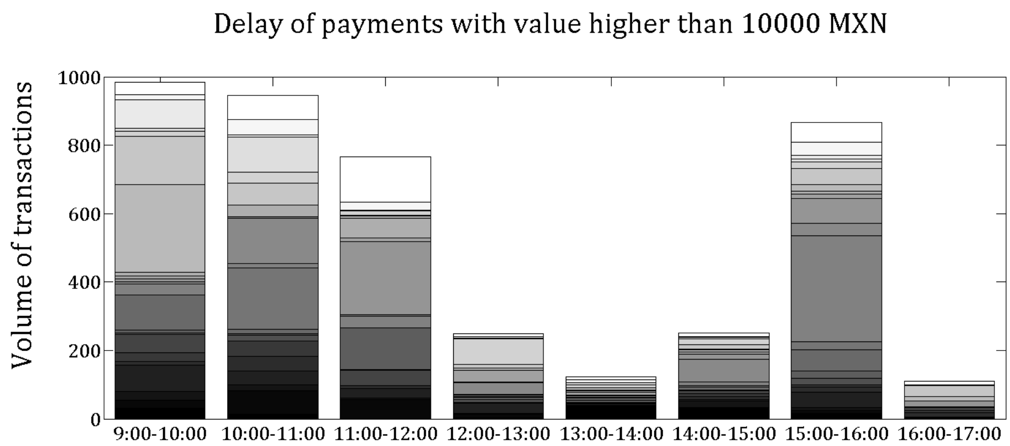
Figure 3. Transactions with value between 1000 and 10000 MXN

Nevertheless, in subfigure 3(b) the pattern in the time structure of the transactions is similar to the one observed in subfigure 2(b), but in this case the highest vulume of the payment orders is observed between 13:00-14:00 and between 12:00-13:00, and the daily volume is steady. Regarding subfigure 3(c), in which the time structure of delayed payments is reported differently from the previously described subset of transactions, here the payment delay is observed on a daily base. Nevertheless, the total correlation coefficient presented in table 4 is the lowest among the four subsets. Furthermore, for this case during the day we observed three hours with negative correlation coefficients. In the previous two cases, the negative correlations are observed between 10:00 and 11:00 and between 13:00-14:00. Here in addition, a negative correlation is also observed between 14:00 and 15:00.



(a)

(b)



(c)

Figure 4. Transactions with value higher than 10000 MXN

Finally the graphs obtained from the subset of transactions higher than 10,000 are presented in figure 4. For this case in subfigure 4(a) we observe a different histogram compared to the previous subsets. In this subfigure, the majority of payments are concentrated in the first decile and the way payments are sent throughout the week does not follow a pattern. This observation is supported by the weekday average presented in table 2, in which no significant difference is observed among the averages of the days of the week. In subfigure 4(b) we notice that the time structure of sending payments is different from the previous three cases. We observe a clear tendency for participants to send large value payments during the morning operational hours. Furthermore as shown in subfigure 4(c) and in table 2 the number of delayed payments is correlated with the volume of the payment sent. This high level of correlation (above 0.70) is not present in the subsets of transactions with lower values. Consequently, the total correlation coefficient is the highest for the payment transactions with value higher than 10,000 MXN,. We can also say that the delay of payments is implemented on a daily basis, but there is no regular pattern in terms of number of payments per day. Among hours before 16:00, the hour with the lowest number of payment delays is between 13:00 and 14:00, but in this case the correlation is not negative, as in the previous three cases.

In order to finalize the observation made in this section, based on our analysis we can conclude that the way payments are sent to SPEI depends on the value of the payment request. In general we observe that participants' behavior is not random with the highest volume of transactions observed on Fridays and the lowest on Tuesdays. Looking at the volume of transactions throughout the different days of the week, according to the data presented in table 2, we can say that payments with value lower than 1,000 follow similar patterns, whereas the volume of payment orders with value higher than 1,000 is steady on different days.

On the other hand, the intraday data included in this section allows us to study the way payments are sent throughout the day, for which we can visualize three patterns:

Payments with value lower that 1,000 MXN. The highest volume processed of those payment orders is observed between 13:00 and 15:00 (please refer to figures 1(b) and 2(b)). In addition, those transactions in general do not have a high correlatation between the number of payments delayed and the number of payments processed (it is around 0.17). Furthermore, this corelation is negative for the hours 10:00 to 11:00 and 13:00 and 14:00. Finally, during the day the highest values of this correlation are observed between 15:00 and 17:00 (please refer to table 4).

Payments with value between 1,000 and 10,000 MXN. In this case the highest volume of transactions processed is oberved between 12:00 and 14:00 (please see figure 3(b)). Furthermore, this set of transactions in general has the lowest correlation between delayed payments and number of payments processed. During the day, this correlation is negative between 10:00 and 11:00, 13:00 and 14:00 and also between 14:00 and 15:00, whereas the highest level is observed between 15:00 and 17:00 hours as presented in table 4.

Payments with value higher than 10,000 MXN. The highest volume of those transactions is processed between 9:00 and 12:00 (please refer to figure 4(b)). Further, this set in general has the highest correlation between delayed payments and number of payments processed, and the correlation is possitive throughout the day. In particular between 9:00 and 12:00 the value of this correlation is above 0.7 and it is high also between 15:00 and 17:00, as we see in table 4.

4. Measuring the delay in terms of time, volume and amount

In order to go further in our analysis, we present in this section three additional measures of the delayed payments calculated for each of the four subsets of transactions defined in the previous section. The measures are calculated on a daily basis and are as follows: the average time of delay per payment order, the proportion of payments delayed per volume of the subset transactions, and the average amount per payments delayed. The results of those calculations are presented in figure 5.

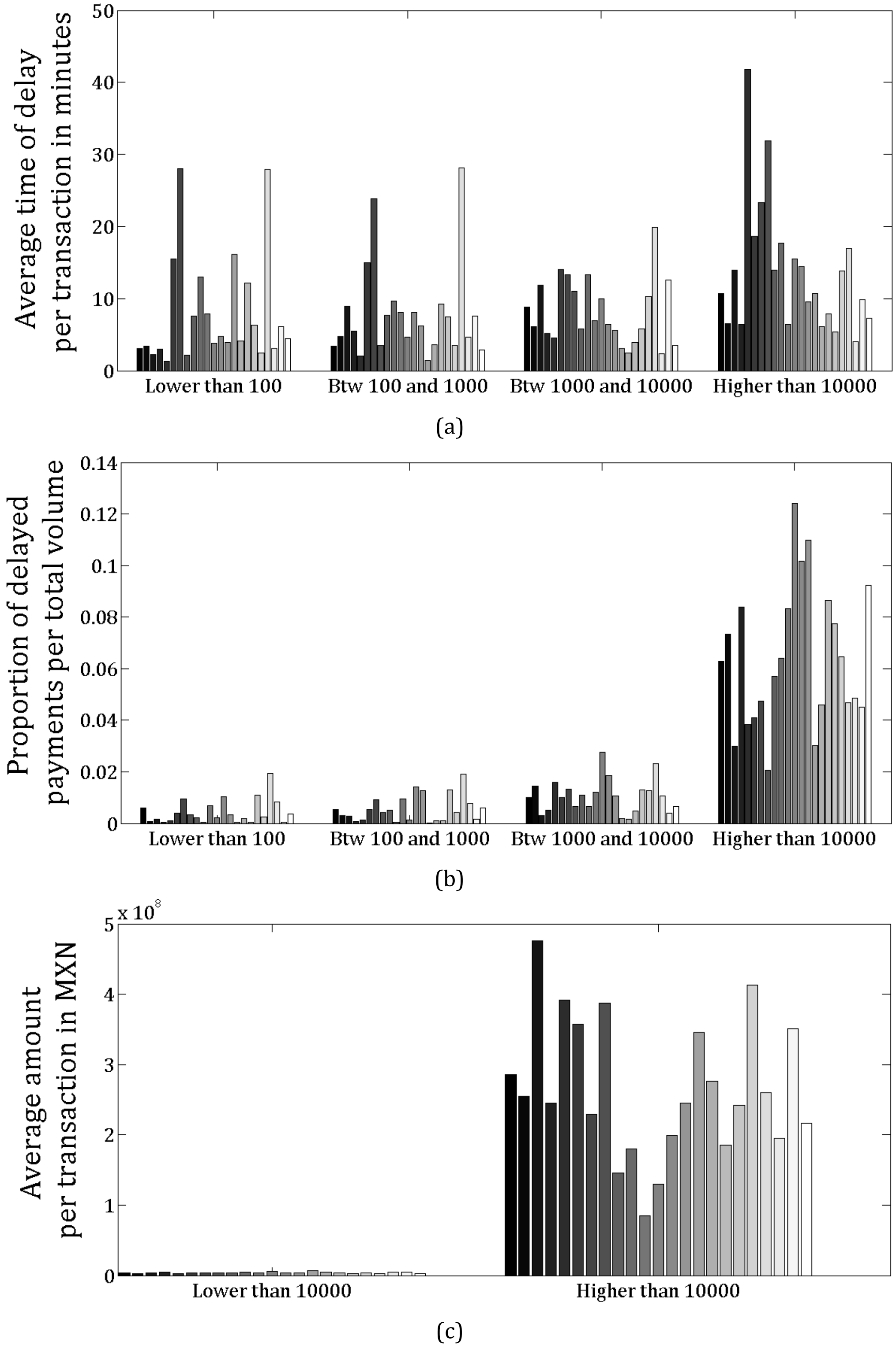


Figure 5. Measuring different aspects of the delayed payments

In subfigure 5(a) we present the average time of delay per transaction calculated for each subset, whereas in table 5 some general statistics are listed regarding this measure. We observe in table 5 that the statistics reported for payment orders with value lower than 100 and between 100 and 1,000 have very similar characteristics, in particular the average, the minimum and the maximum. Regarding the transactions with value between 1,000 and 10,000, we can say that the maximum time of delay is the lowest among the four subsets. This observation goes along line presented in the previous section, in which we said that this subset of transactions reported the lowest number of payments delayed. Finally regarding the transactions with value higher than 10,000, we observe that those payments on average spend more time waiting to be settled and the minimum and maximum time of delay is considerably higher than for the rest of the transactions.

Table 5. Statistics on the average time of delay

	>100	**100-1000**	**1000-10000**	**<10000**
Average	7.93	7.81	8.12	13.60
Median	4.48	6.17	6.41	10.71
Std. Dev.	7.63	6.54	4.56	8.98
Min	1.32	1.42	2.34	4.05
Max	28.03	28.16	19.91	41.83

Next, in subfigure 5(b) we present the proportion of the number of payments delayed in comparison to the total volume of transactions. In table 6 and 7 are shown the general statistics regarding the number of payments delayed and the proportion of the number of payments delayed, respectively. We observe in subfigure 5(b) that the patterns of payment instructions with value lower than 100 and instructions with value between 100 and 1,000 are very similar. With respect to the subset of transactions with value between 1,000 and 10,000, we notice an increase in the proportion of payments delayed, but the share is still considerably lower than the proportion of payment orders delayed in the subset of transactions with value higher than 10,000. This subfigure and the data presented in table 7 clearly show that payments with value lower than 1,000 follow similar patterns, presenting the lowest proportion of delayed payments (on average 0.0043 and 0.0056 respectively). In addition we observed that the proportion of delayed payments doubled for the subset of transactions with values between 1000 and 10000 (on average 0.0106), and increased significantly – six times – for the payments with value higher than 10,000 (on average 0.0641).

Table 6. Statistics on the number of payments delayed

	>100	100-1000	1000-10000	<10000
Average	901	199	65	183
Median	387	142	59	170
Std. Dev.	1043	232	41	102
Min	53	6	9	50
Max	3867	959	160	399

Table 7. Statistics on the proportion of the number of payments delayed

	>100	100-1000	1000-10000	<10000
Average	0.0043	0.0056	0.0106	0.0641
Median	0.0024	0.0042	0.0105	0.0627
Std. Dev.	0.0047	0.0052	0.0066	0.0273
Min	0.0004	0.0002	0.0015	0.0206
Max	0.0194	0.0192	0.0275	0.1241

Finally we look at the average amount per transaction, which in subfigure 5(c) is presented only as a division between payment orders with value higher than 10,000 and those orders with value lower than 10,000. In table 8 we present the statistical measures for the four subsets of transactions, which are shown as the total aggregated value of transactions. This data suggests that delayed payment orders of large value could have a significant impact on the liquidity usage through the day.

Table 8. Statistics regarding the average amount of delayed payments

	>100	100-1000	1000-10000	<10000
Average	16,803.54	364,795.27	3,620,199.51	264,973,104
Median	16,711.15	338,263.46	3,353,865.1	245,633,951
Std. Dev.	4,172.35	83,749.86	1,005,163.05	98,412,065.3
Min	9,026.01	273,173.03	2,346,977.92	85,208,203.5
Max	24,759.30	609,629.35	6,671,626.71	475,550,938

5. Stressing the intraday liquidity

In this section we present the results of a simulation test aimed at evaluating the impact of low value payments on the settlement of large value payments, given that intraday liquidity is limited. In order to reproduce the operational conditions of SPEI, we use an artificial environment. We elaborate the simulation scenarios with the same 23 days of transactional data, which are structured in four sets, delimited according to their value: set one includes all payments; set two is a subset of payments with value higher than 100 MXN; set three is a subset of payments with value higher than 1,000 MXN, and finally set four is a subset of payments with value higher than 10,000 MXN. In table 9 we present the size of the subsets per day. We measure the effect of settling a large volume of low-value payments in real time by calculating the settlement delay $\mathcal{V}$ of the large value for each subset previously defined.

Table 9. Number of transactions per subset

Day	All Payments	Payments >= 100	Payments >= 1000	Payments >= 10000
07.04.2010	195,637	31,280	7,116	2,136
08.04.2010	195,578	33,211	7,563	2,318
09.04.2010	277,326	41,367	8,559	2,608
12.04.2010	202,695	33,616	8,556	2,758
13.04.2010	179,899	31,728	8,140	2,577
14.04.2010	229,436	36,093	8,219	2,322
15.04.2010	279,731	38,203	8,481	2,526
16.04.2010	305,347	43,045	8,876	2,621
19.04.2010	205,322	36,703	9,363	2,981
20.04.2010	181,098	30,611	7,804	2,999
21.04.2010	174,978	30,525	7,464	2,633
22.04.2010	193,068	35,190	9,041	3,215
23.04.2010	274,774	42,249	8,861	2,792
26.04.2010	198,330	34,711	8,760	3,061
27.04.2010	182,009	32,532	8,020	2,645
28.04.2010	196,682	35,879	8,562	2,692
29.04.2010	269,387	44,756	10,374	3,572
30.04.2010	416,860	59,374	12,853	4,023
03.05.2010	195,294	31,954	8,601	2,807
04.05.2010	184,136	30,388	7,952	2,823
05.05.2010	217,316	39,758	9,845	2,836
06.05.2010	208,648	34,747	8,706	3,047
07.05.2010	290,832	43,507	10,082	3,665

In order to perform the liquidity stress test, first, according to equation 4 we calculate for each of the subsets above the minimum required level of participants' funds, ℓ_i^{min} for which all transactions are settled for each subset. Here we assume that the settlement order of the transactions will not be modified, and that the number of payments will not be reduced by the changes in the intraday liquidity level. This is a very strong assumption, as other studies have proven that under conditions of stress, participants' behavior changes and not only the order the payments sent could change, but depending on how severe the stress conditions are, the most probable scenario could be to reduce significantly the volume of transactions[17]. Nevertheless, given that we do not have insights which would be the reaction of the participants in SPEI, we decided not to modify the volume of transactions, or the order of payments. Nevertheless due to the reduction of available liquidity, the structure analyzed in the previous sections is no longer the same.

Table 10. Statistics on the average settlement delay

		Payments >=100		Payments > = 1000		Payments >10000	
		Settled with all payments	**Settled separately**	**Settled with all payments**	**Settled separately**	**Settled with all payments**	**Settled separately**
$\mathcal{V}$	**Average**	11,487	11,636	11,179	11,198	11,138	11,100
	Std. Div.	3,331	3,328	3,497	3,592	3,493	3,321

For our study, we use the simulator with transactions corresponding to each of the specified subsets and calculate the settlement delay $\mathcal{V}$ for subsets two, three and four. Then we compare each one of them to the settlement delay $\mathcal{V}$ of the first subset. In order to make the comparison more accurate, we include in each of the three cases only the payments corresponding to the transactions with higher value. Thus from the subset of all payments only the transactions with higher value are included, which correspond to the transactions of the compared subset. We present the comparison in the settlement delay $\mathcal{V}$ in figures 6, 7 and 8. In addition in table 10 we present the average and the standard deviation of $\mathcal{V}$ for the three cases of study in billions of MXN.

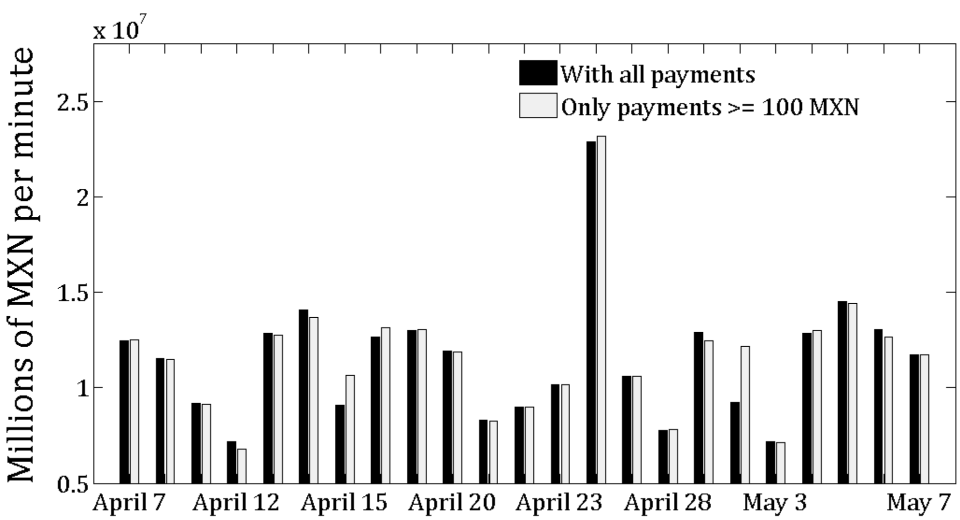


Figure 6. The settlement delay $\mathcal{V}$ in conditions of stress (first comparison)

We observe in figures 6, 7 and 8 and the average presented in table 10 that settlement delay $\mathcal{V}$ is not significantly modified by the inclusion of low value payments. We notice that the sequence and the size of payments on a particular day are factors determined more significantly by the millions of MXN per minute delayed than by the division by value for the subsets of transactions.

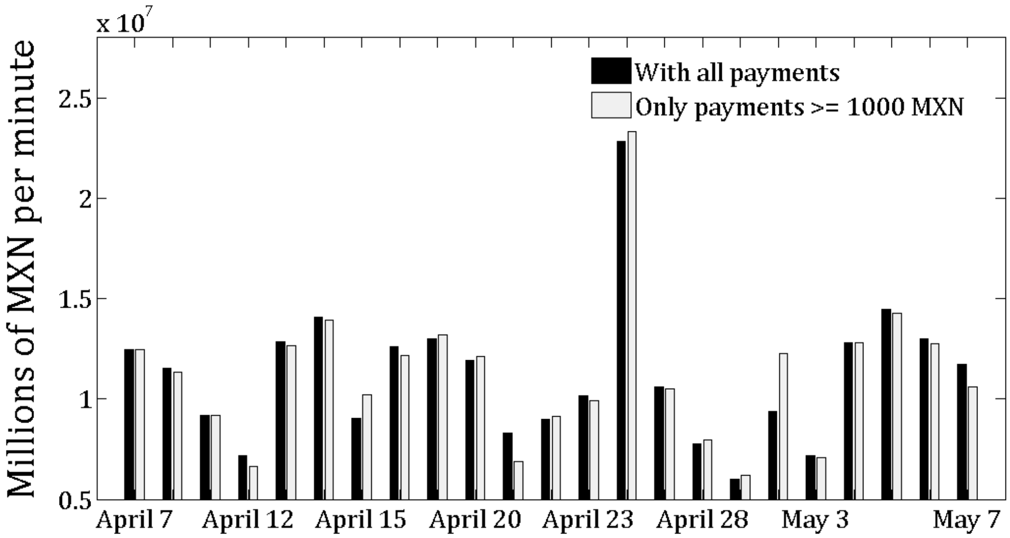


Figure 7. The settlement delay $\mathcal{V}$ in conditions of stress (second comparison)

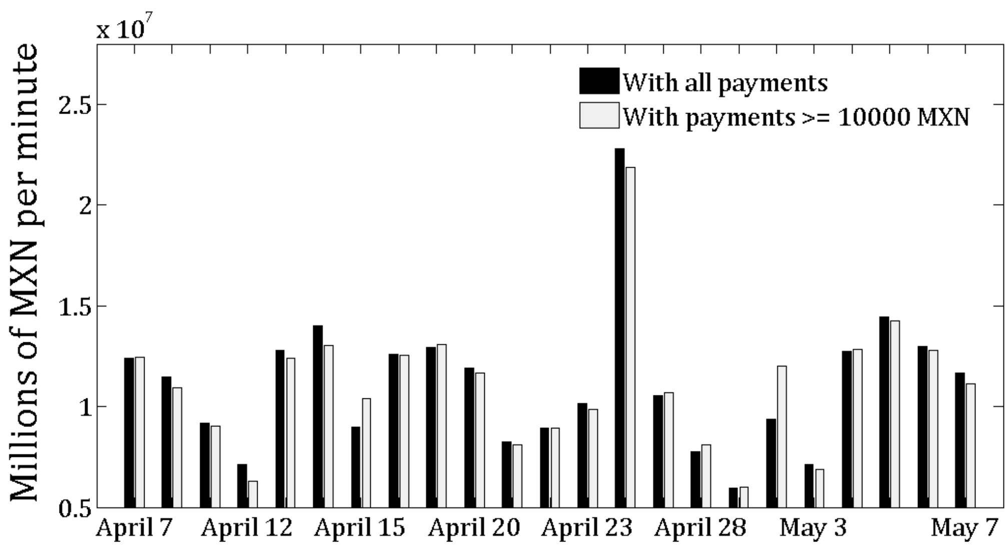


Figure 8. The settlement delay $\mathcal{V}$ in conditions of stress (third comparison)

6. Conclusions

This is among the first studies of intraday liquidity analysis of the Mexican Large Value Payment System SPEI. This paper looks at the number of payments delayed from two perspectives. The first objective is to get further insight regarding the motivation of the participants in SPEI to delay payments under various operational conditions. The other is to evaluate the impact of low value payments in the settlement of large value payments under conditions of stress.

To that end we elaborate two case studies using thirty days of transactional data taken from SPEI between April 7 and May 7, 2010 corresponding to the payment orders performed from 9:00 a.m. to 17:00 p.m. each working day. Both cases are performed in an artificially created environment that reproduces the operational conditions of SPEI. The first case allows us to make observations on the emerging patterns of participants' behavior given the empirical evidence by dividing the transactions in four subsets determined by their value. In particular, for each of these subsets we look at three aspects of the payment orders – the histogram, the time structure of transactions, and the time structure for the number of payments delayed. We also include for each subset a weekday average and standard deviation in table 2 and daily average and standard deviation in table 3. Furthermore, we calculate a correlation coefficient between the number of payments delayed and the number of payments processed. Those coefficients are presented in table 4.

What we conclude from our observations is that a clear weekly regularity is observed in the volume of payments with value lower than 1,000 MXN. With respect to the volume of large payments this pattern is not observed. Further, regarding the time structure throughout the day for sending payments, we observe that it follows different patterns for large and low value payments. In particular we can divide the transactions into three categories – payments lower than 1,000, transactions between 1,000 and 10,000 and payment requests higher than 10,000. Moreover, the majority of large value payments are sent during morning operational hours, in which a high correlation coefficient between delayed payments and number of payments processed, is observed. On the other hand low value payments have a peak observed between 13:00 and 14:00, which is negatively correlated with the number of payments delayed during this hour.

The second case study has allowed us to evaluate the settlement delay of millions of MXN per minute delayed $\mathcal{V}$ measured under conditions of limited intraday liquidity. According to the results, we have observed that low value payments do not increase the settlement delay. Furthermore, what determines the level of $\mathcal{V}$

are the sequence and the size of payment orders on a particular day, primary determined by the large value payments.

As a final remark, we believe that more studies related to the intraday liquidity management are required in order to get further insights on participants' behavior. One possible extension to the present work could be to analyze intraday liquidity usage in relation to the observed delayed payments. We also could apply the empirical analysis to a more extensive period of time, which statistically will be more accurate.

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