On the optimization of an ATM network: forecast of cash demand and analysis of customer habits

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Abstract – An automated teller machine (ATM) is still a very popular mean of cash withdrawals in some countries. In this paper, an overview of its specialities in Lithuania is provided, together with possible problems that may be encountered in the modeling process, including demographic, economic, technical, and political factors. A technical implementation of ATM network simulator is proposed in the paper using MathCad software to forecast cash demand in the ATM network.

Key-Words – ATM, cash demand, optimization, maintenance, traveling salesman problem.

I Introduction and main abbreviations

A short introduction to an automated teller machine network (in the further text - ATM network) is provided in view of its specialities in Lithuania and possible problems that may be encountered in the modeling process, including demographic, economic, technical, and political factors.

Main abbreviations used in this paper:

1. ATM - automated teller machine. Cash withdrawing machine.
2. RATM, CR - recycling ATM, cash recycler - both cash withdrawing and cash depositing machine.
3. BNA - bunch note acceptor, cash depositing machine.
4. CIT Company (*a.k.a. Cash in Transit*) - company that provides maintenance services for an ATM network.

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II Motivation

The need for optimizing an ATM network and forecasting of cash demand, based on customer habits, is motivated by the following facts:

1. In Lithuania ATMs still play a very important role as the level payments by cards is quite low (during the year of 2013, 75 percent of customers gave the priority to cash rather than to credit/debit cards). Having this in mind, a well operating ATM network is very important since it ensures both cash availability 24/7 and a proper image of the bank to customers.
2. Failures of machines are that operate in the ATM network (approx. probabilities): 0.5 ATM/month, 3.5 RATMs/month, 3 BNAs/month.
3. It is neither safe nor smart to keep a large quantity of excess cash in the ATM machines, especially whent the annual interest rate is high.
4. Modeling of an ATM network, based on customer habits, is a good stimulus to start developing genuine software relying on *Big Data*, which even may lead to better results than the CIT company is providing.

III A short review of ATM network investigations

There exists only a small number of papers regarding the optimization of ATM network maintenance. In 2007, Rimvydas Simutis *et al*, published a paper ([5]) about forecasting cash demand in ATM network, based on artificial neural networks. Suggested solution is based on merging up two different artificial intelligence methodologies, neural networks and multi-agent technologies. The paper states about the possibility to save approximately 3 Million EUR per year of total maintenance costs of an ATM network.

Another significant work in this field, that must be mentioned, is a stochastic approach to cash management in ATM network wirtten by Jordi Castro ([1]). In this paper he analyzes two main issues: cash management in ATM network and the compensation of credit card transactions. In both cases a decision must be taken according to customers' cash demand, which is uncertain and can only be obtained from historical data. The author develops a discrete probability distribution of this demand, which allows the application of stochastic programming techniques.

An interesting approach is provided in the paper by K. Venkatesh et al ([7]), where ATMs are splitted into clusters having similar withdrawal patterns. To retrieve withdrawal seasonality parameters, the author represents a time series model for each cluster of ATMs.

The most advanced approach regarding the forecast of cash in the network is provided by Teddy and Ng ([6]), since the authors propose a novel local learning model. Pseudo self-evolving cerebellar model produces accurate forecasts of cash demand from 111 empirical daily ATM cash withdrawal series. The evaluation results, based on empirical daily cash withdrawal series, showed that the forecasting capability of such a model exceeds the benchmark local and global-learning based models.

Although the main variable (cash demand), is the same in all the papers cited above, and in our paper as well, but quite a different approach is analyzed in our paper, since the focus is not on the bank's, but on the CIT company's side.

Such an approach is provided by Y. Ekinci et al ([3]) where ATM network maintenance of Istanbul is investigated. The author also proposes grouping ATMs by location clusters and optimizing the aggregations of daily cash withdrawals.

Other, although not directly related works in this field include automatic monitoring system approach by S. Nakamura et al ([4]). The author observes the issues which is also in our field of investigation, e.g., ATM network maintenance on weekends and holidays and forecasting approximate costs for such operations.

Finally, an interesting economic approach is investigated by Donze and Dubec ([2]), where they examine the effects of regulating the interchange fee at cost on ATM deployment. It is proved that such a regulation makes the interchange fee decrease over time, which in turn reduces banks' incentives to deploy ATMs.

IV Forecasting cash demand in an ATM network: the main factors

Cash demand in an ATM network can be modeled based on experts' opinion, regression models or 3^{rd} party software (such as "Wincor-Nixdorf"), artificial neural networks, etc. Essential factors having impact on cash demand are (ordered from the highest to lowest impact) as follows:

1. Period of salary and pension payments.
2. Weekend cycle - the increased number of withdrawals both on Friday and Monday.
3. National holidays.
4. Demographic base of customers and their habits.
5. Political situation and stability in the country.
6. Image and perspective of the bank.
7. Annual interest rate.

Remarks. The most essential factor for cash demand in the ATM network is the period of pension payments (in Lithuania it is usually between the 10th and 12th day of each month). Factors 5-6 are not that important: even if any of *force majeure* situations did happen, the ATM network would operate on quite a different set of rules. Factor 4 is more important in a long run of time.

V Current situation in Lithuania

Since the annual interest rate of 2013 (EURIBOR) reaches only 0.5 percent, it strikes a note that it might not provide any significant modeling results in the current economic cycle. However, it is important to include the annual interest rate into the modeling process with a perspective in a longer run of time. Another important factor is the distribution of cash circulation, based on the nominal value of banknotes. This paper is written within the period of currency transition from Lithuanian Litas (LTL) to Euro (EUR) from the 1st of January, 2015. The experience of such transitions in Estonia and Latvia has showed that it highly affects the ATM network too, mainly because of two factors:

1. The number of nominal values of EUR banknotes (5,10,20,50,100,200,500) is higher as compared to LTL (10,20,50,100,200,500). Actually it is more like (20,50,100,200,500) as the smallest amount possible to withdraw by ATMs in Lithuania is 20 LTL.

2. During the period of currency transition, prices of goods and services will remain more or less equal to at before the transition, so these conditions being valid, customers will naturally get used to the banknotes of smaller nominal values. For example - the most popular LTL banknote, 200 LTL, will be probably replaced by 20+20+20 EUR or 50+10 EUR (official EUR/LTL exchange rate is 3.4528)

Distribution of LTL banknotes. Data provider: Bank of Lithuania (2012 December)

Amt	Qty, th	Sum, kLTL	Part of Total (percent)
10	10056.1	100561	11.57
20	11161.1	223221	12.84
50	9213.8	460689	10.60
100	20001.3	2000131	23.00
200	32969.2	6593832	37.92
500	3549.4	1774714	4.08

Distribution of EUR banknotes. Data provider: ECB (March 2014)

Amt	Qty, th	Sum, kEUR	Part of Total (percent)
5	300184.9	1500924.3	10.57
10	696535.1	6965350.8	24.53
20	826907.6	16538151.4	29.12
50	877374.7	43868733.3	30.89
100	113117.4	11311738.3	3.98
200	6886.7	1377333.4	0.24
500	18933.7	9466843.5	0.67

VI Maintenance of an ATM network and its technical specification

To sum up the introduction part, it is quite easy to notice that there are 4 possible cash flows in the ATM network:

1. CIT company's deposits.

2. CIT company's withdrawals.

3. Customers' deposits.

4. Customers' withdrawals.

The CIT company usually operates according to a plan which is coordinated in advance (e.g. one concrete machine in the ATM network gets a fixed number of maintenance cycles during one month).

Possible risks:

1. *Out-of-plan* calls for CIT company's maintenence (extra maintenance) are unproportionately expensive. Having that in mind it is reasonable to put cash in every ATM more than needed during every maintenance cycle (especially when annual interest rate is low).

2. *Wall ATMs* (located in shopping malls, cafes and other places that do not operate 24/7). This area of ATM network needs more attention to keep it in service on weekends and non-working hours.

VII Customer habits and exceptions

As mentioned in the introduction of this paper, the maintenance of ATM network depends on habits of customers, too. Here are some examples:

1. Increased number of customers' deposits at the end of month which increases the risk of over filling the depositing cassette.

2. Smaller withdrawal amounts at the end of month which affects the demand for banknotes of lower nominals and increases the probability of extra maintenance.

It is possible to affect the habits of a customer by changing the standard amounts of cash withdrawal which are displayed in the main window of an ATM machine.

VIII Possible fields for investigation

To sum up the current economic situation in Lithuania and the technical specification of an ATM network, possible fields of investagation can be:

1. ATM network maintenance on weekends.

2. RATM usage optimization to avoid its overfilling.

3. Optimization of the CIT company's cycle, based on *Big Data* and the travelling salesman problem (TSP).

To simplify the modeling process, all the investigation fields stated above may be processed only in the cash-withdrawing ATM network, later on adding RATMs and (or) BNA cash flows.

IX Theoretical approach to an ATM network simulator

In this section, we introduce the approach of optimizing the ATM network from the viewpoint of the CIT company. The main target of the ATM network simulator is to provide maintanence schedule of the network, for, e.g., one week.

First, we define some general rules tol be used later:

1. A part of the costs of the CIT company is a fixed percentage of unused money in ATM that is returned after the maintenance cycle (collection cost). In other words, the bank pays the fixed percentage only for the amount that has been actually withdrawn from an ATM, (e.g., if 1M was put in the beginning and 300k was returned by the CIT company, the bank pays the fixed percentage from 700k).

2. As mentioned above, *Out-of-plan* calls for CIT company's maintenence (extra maintenance) are unproportionately expensive and one call for a particular ATM can cause delays in other parts of the ATM network, which is also important thing to consider when modeling an ATM simulator.

3. Taking into consideration two items mentioned above, the outcome of optimzation should ensure the optimal regime of maintenance, which means enough work for the company everyday, excluding as much as possible duplicate visits (e.g., going to the same place more than once in a week).

4. Due to the complexity of modeling and possible issues, an ATM network without customers' deposits will be analysed.

X Main components of an ATM network simulator

An ATM network simulator includes several components that help to make it as realistic as possible. The first component is the mean customer flow function, which describes how many of them use an ATM machine within an hour. It shows the average load of ATM during work hours.

We chose an ATM which serves from 10 to 30 customers per hour. Thus, the customer flow function acquires the following form:

$$\lambda(i) = 20 + 10 \cdot sin(\frac{\pi \cdot i}{12}) \tag{1}$$

As mentioned in the previous sections, the whole ATM network behavior has strong dependencies on the calendar day too. So another component, having impact on the whole network, is described as the coefficients of intensity (compared to the average mean network load):

1. 1.2, if the current calendar day is Sunday or it is between the 1st and 10th day of the month.

2. 1.5, if the current calendar day is between the 10th and 11th day of month, as well as the days before the long weekends and national holidays. For example, in Lithuania it is the day of Christmas Eve, December 24 (and the day before, the 23rd of December), and the days before the national holidays in summer: June 22 and August 14.

3. 1.35, if the current calendar day is Saturday or it is between the 17th and last day of month.

XI Modeling of an ATM network simulator using MathCad software

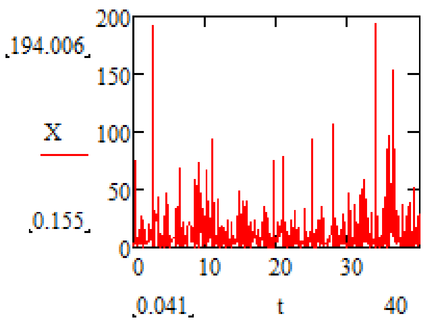
To begin with, let us declare that time distribution of customers' withdrawals is exponential (time periods between each withdrawal are a Poisson process). Amounts of withdrawals are denoted as ξ and have the exponential distribution with the mean mm and the standard deviation ss. That is, $\xi = exp^{rnorm(1,mm,ss)}$

Time distrbution of customers' withdrawals is of the following form:

$$dt = -\frac{(ln(rand(0,1))}{\lambda^*} \tag{2}$$

We relate the intensity λ^* to a combination of both customer flow function (1) and a sub-program of dependencies on the calendar day (both are described above).

Withdrawal amounts are simulated by the Monte Carlo method and can be generally seen as in the figure below (X is withdrawal amounts, t is time in days).



XII CONSIDERATION OF FINES FOR MISSED COLLECTION AND COLLECTION OF LARGER AMOUNTS

In this section, we consider an empirical approach to find the CIT company an optimal proportion of missed collections and larger collection amounts. We arrange the maintenance schedule, based on the goal equation that involves the average turnover of primary observations, lia, newly generated observations M, $fine$ for the missed collection and the fixed percentage $fixedpct$ for collection of unused money. Generally speaking, the equation is of the following form:

$$f(M, fine, fixedpct) = 1 - \exp^{\frac{-M}{lia}} \cdot fine \qquad (3)$$

$$- \exp^{\frac{-M}{lia}} \cdot fixedpct$$

The Monte Carlo-based maintenance algorithm is provided at the end of this paper and is dependent on:

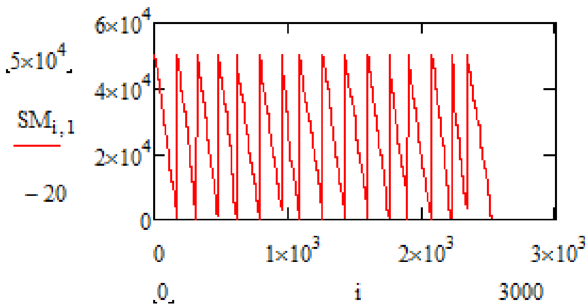
1. ll - a combined intensity function λ^* both on customer flow function (1) and the sub-program of dependencies on the calendar day (provided at the end of this paper).
2. Exponential distribution parameters for simulating the amounts of withdrawals (mean mm and standard deviation ss).
3. The number of simulation days T.
4. $fine$, the amount of money charged for the CIT company's failure to change the cassette of ATM in time (fine for the missed collection).
5. $fixedpct$, collection costs (percentage from the remaining money in ATM, in case the CIT company arrives to change the cassette of ATM too early).

The whole algorithm, explained in short, consits of the following parts:

1. At the beginning of the cycle, ATM contains the maximum amount of money that possible to contained ($Cassette\ Capacity$).
2. Simulation cycle T is a fixed length variable, and it is chosen based on how long we want to simulate, for example one week (in hours), $T = 144$.
3. The situation in ATM is simulated, based on the component of the average customer flow and dependencies on the calendar day (this subprogram is provided at the end of this paper).
4. Time periods are modelled by the formula described above, where λ^* is a function ll of the calendar day $ll(t)$ and average customer flow (1).
5. Withdrawal amounts are modelled as a Gaussian process: $\xi = exp^{rnorm(1,mm,ss)}$
6. Withdrawal amounts are subtracted from the total amount of money present at certain ATM. In the first step, it is equal to maximum amount that a single cassette of an ATM can contain ($Cassette\ Capacity$).
7. ATM opearates until the goal function (3) becomes smaller than zero. At that time cassette is changed and +1 is added to the cassette count (KST). Then, ATM is deposited with the maximum amount again and the cycle continues till it reaches T.

XIII MODELING RESULTS OF THE MAINTENANCE CYCLE

The general idea of this exercise is to predict situations when ATM runs out of money sooner than expected, and, as a result,to help the CIT company to be in the right place before the critical situation happens. In the real life ATM behavior looks like in the figure below. As we can see, sometimes the amount of money in the cassette reaches the zero point, but sometimes does



not.
To evaluate how long the resources in the network will last, we need to look at the average turnover of each ATM in the network. Having these numbers, we can

calculate the goal function (3) and to prioritize the queue of ATMs which the CIT company should visit. Another important component is a geographical context, that will not be discussed much in this paper. But it is obviously useful to visit not only those ATMs which are running out of money, but also that which are on the same way too. That would prevent from possible duplicate visits to the same area in the same cycle.

XIV Optimization of costs for the CIT company

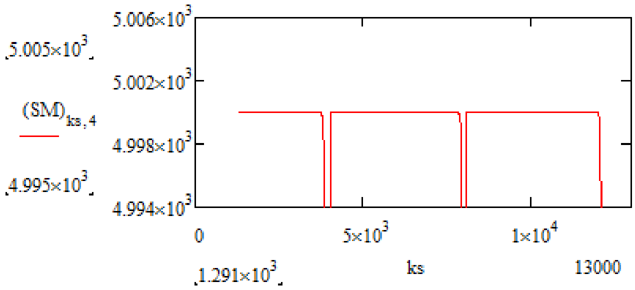
As mentioned above, there are a few important things which must be considered when optimizing total costs for the CIT company.

1. The first thing is to arrange the maintenance schedule which inludes as little as possible ATMs that ran out of money before the arrival of the CIT company. This issue is based more on the geographical context of ATMs. Various combinations of ATM visits may be considered based on the distance from each other. Also, when visiting ATMs in a certain area, a good idea is to include those which are in the near radius from the maintenance area as well. That prevents from duplicated visits, mentioned earlier in this paper.

2. The second important thing, and more sophisticated, is not only to concentrate on ATMs running out of money, but also to monitor the goal function to be as small as possible (but not smaller than zero) for the day of maintenance. Obviously, there is a high risk for ATM to run out of money before the CIT company arrives.

Using the goal function (3) with the parameters $fixedpct$ and $fine$, we can simulate the situation in each ATM to find the critical number of transactions when the CIT company should react and replace the cassette in a particular ATM. Sometimes, it may be more convenient for the CIT company to pay the fine for missed collection than to monitor the situation at all. However, this scenario is not likely to be possible in real life, since the fine is usually higher than the fixed percentage which should be paid.

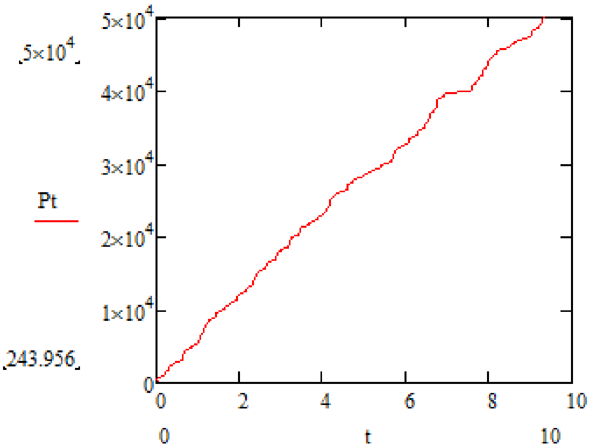
Let us simulate the situation in one ATM for one week ($T = 144$). With the average turnover of primary results $lia = 245$, $fixedpct = 0.1$ and $fine = 5000$ the ATM will need one change of the cassette and will last for 197 hours (approx 8 days), and will handle approximately 4000 transactions. Such results help to prioritize the maintenance schedule, since the CIT company knows the day when the cassette will be needed to be changed again. The situation may be simulated for the whole month (576 hours). A picture below shows the dynamics of the goal function (3), in other words, it illustrates how many transactions ATM can handle within each cycle of the new cassette:



As we can see, the total number of 3 cassette replacements will be needed and ATM will handle approximately 13000 transactions.

XV Empirical distribution of ATM

Finally, we may have a look at the empirical distribution of ATM. In reality, these distributions are usually different among ATM machines situated in various locations of the network as it is highly related with the popularity of a particular geographic area (city, rural area, shopping center, etc.).



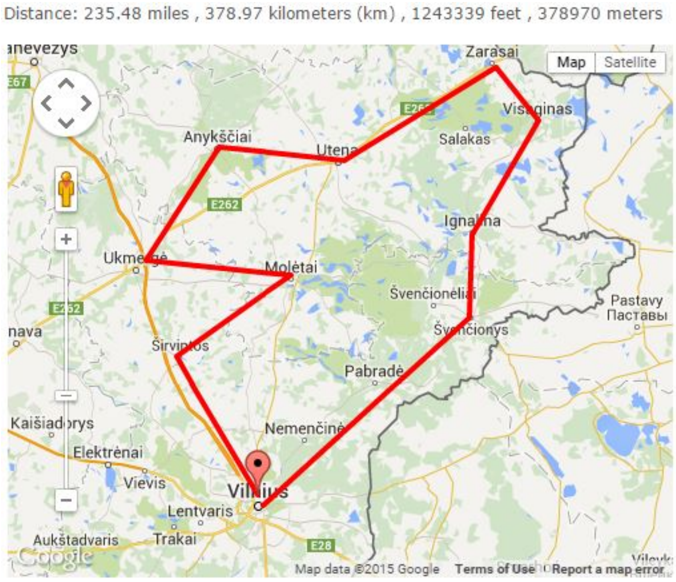
Knowing approximate probabilities how long each ATM cycle will last on the scale of time, we have all the components for a logistic exercise. The main variable is the value of goal function (3), since it can be diffucult to forecast the remaining amounts ϵ because of different withdrawal intensities on different calendar days. A good solution would be to look at empirical distributions of ATM network and their goal functions classified into 4-5 groups, based on calendar days. The decision where and when to go for the CIT company would be based on these distributions, as well as the fuel cost and the number of possible additional ATMs that need to be visited in the same area.To evaluate such maintenance scenarios, it is needed to have a graph with distances between each machine in the network and also to include the cost for preparing new cassettes for the new cycle of maintenance. Then we can solve the classical traveling salesman exercise and provide possible Hamiltonian cycles in the graph of distances. Each cycle, or maintenance itenerary, would have its own cost and and fixed percentage for each scenario for collecting unused money ϵ and fines for missed visits would be different, since it is necessary to solve an exercise when the number of machines that need to be maintained is higher than the CIT company can handle. An example of graphical implementation of such a task based on statistical package R is provided in the last section of this paper.

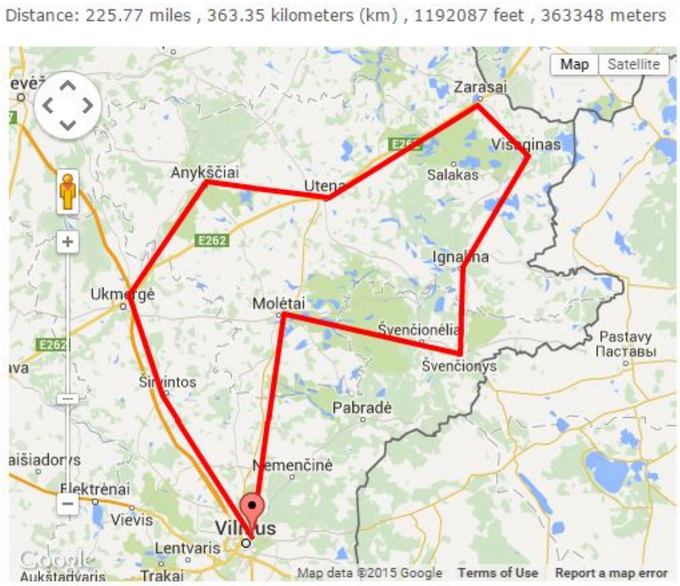
XVI Proposal of a logistic exercise with an ATM network, based on Big Data and statistical package R

A theoretical approach of a logistic exercise, based on Big Data and statistical package R is provided in this section.

The ATM network itself can be seen as a really huge data mine, since millions of transactions happen in it every day, and sometimes 10 thousand or even higher rate per second is reached. It seems nothing but a possiblity to handle it by using the techniques of Big Data and powerful open source tools, such as statistical package R. Big Data techniques may be used both inductively and deductively. For example, forecasting the aggregated cash demand in the network or providing the most commonly used withdrawal amount for, say, each particular customer when he or she puts the card into ATM. These solutions may provide huge advantages both for operation of the ATM network and its maintenance and, certainly, customer satisfaction.

One of the exercises can be already mentioned classical Travelling Salesman Problem (TSP) because the ATM network itself looks as a map of the cities, for example, the Vilnius region. We also define a graph with distances between cities *geo* provided at the end of this paper. A few possible iteneraries are as follows:





As stated previously in the paper, in one particular area ATM machines are often maintained in the usual order, one after another. As mentioned before, the CIT company would rather go to a number of additional nearby ATMs (with a higher risk of running out of money) on the same maintenance cycle than visit the same location in the near future again. Knowing the real-time situation of ATM network and its transaction history, it is possible to forecast the critical number of transactions for each ATM on the scale of time. That would obviously provide a more effective and cost-optimized schedule. The next step can be to add the geographical-based component, such as ATM coordinates on the map, because then it would be possible to calculate the 'worthiness' component of the CIT company's visit to a certain ATM. It seems that such a mechanism can require a powerful software to be handled. Although it can be easily feasible using open source statistical package, such as R library *Datatable*. The result can be trajectories on the graphical map of the Vilnius region. In our case, having the dataset of ATM network usage, critical numbers of transactions and ATM coordinates on the map, it can be possible even to create an interactive interface which would help CIT companies to be at the right place, at the exactly right moment.

XVII Concluding remarks and notes for the future research

During the writing process of this paper, Lithuania became a member of Eurozone from the 1st of January 2015, but the exercise of the CIT companies' cost optimization remains even more relevant in 2015. A special attention should be paid to RATM machines because they can be under a high risk of congestion, as there will be more banknotes in the market, which means nothing else than a higher workload for CIT companies, since changing of cassettes will be more frequent. Euro change might also result in various changes according to customers' habits. Although they were absent at the beginning of 2015, the amount of cash in the market seems to remain lower than in the year 2014 because some previously conservative customers tried payments by cards. However, the forecasts of bank experts declare that the amount of cash in the market should reach its previous levels of 2014 sooner or later. It means that CIT companies eventually will have the same or even higher workload.

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