ABSTRACT
Under the Bank of Thailand’s new banknote circulation scheme, banknotes are distributed from the Note Printing Works to 11 banknote management centers, each of which serves multiple cash centers of the commercial banks. Meanwhile, each of those cash centers serves multiple bank branches, which provide cash-related services to the individual customers. We focused on the planning and forecasting problems of the supply chain of Thai banknotes, especially those confronting the central bank.

The planning and forecasting problems for banknote management have interesting elements, features and requirements. Some of those requirements are the responsiveness and efficiency of production and distribution planning and the exceptional service level that the central bank provides to the commercial banks. In practice, there are three planning and forecasting problems. They are the problems of demand forecasting, distribution planning and production planning. We proposed solutions to these problems. The solutions themselves can then be developed into a web-based software for banknote management.

To solve the demand forecasting problem, we standardized the forecasting procedures that were used previously. The techniques that we considered include regression, moving average, and time-series analysis. For the distribution problem, we considered both inventory and transportation costs in order to determine the optimal frequencies and lot sizes for banknote distribution to the banknote management centers. These economic order quantity analyses and results from the forecasting problem then lead to a banknote distribution plan. Finally, we used data on lead times, production calendar, machine availability, process capacity and production line setting to develop a banknote production plan.

KEY WORDS
Forecasting, Planning and Banknote Management

1. Introduction
The Bank of Thailand (BOT) has proactively responded to the continuous, demand-driven growth of banknotes in circulation by improving the distribution part of its supply chain. The central bank’s primary objectives are to increase the efficiency and to redefine its role in banknote management. The latter objective is comparable to what have been implemented in many industrialized nations. During the past few years, there have been significant changes at the operations, tactical and strategic levels of banknote management. In this paper, we focus on how newly available information regarding banknote inventory and transactions can be used to improve the responsiveness and overall efficiency of the banknote supply chain, especially on the parts that involves BOT.

Prior to November 2004, banknotes were distributed through BOT’s head and regional offices and through the Ministry of Finance’s provincial treasury offices (PTO’s). Cash centers of the commercial banks in the provinces relied heavily on PTO’s, which acted on behalf of BOT in banknote receiving and disbursing operations. Under the scheme, commercial banks’ cash centers deposited and withdrawn banknotes at a local PTO, which then transported the banknotes to one of BOT’s offices. Banknotes were then sorted by BOT. Fit and new banknotes were distributed through the PTO’s back to the commercial banks’ cash centers.

Under the new scheme, implemented since November 2004, commercial banks are responsible for banknote sorting. The central bank expects the deposit of only unfit and excess fit banknotes at its 11 banknote management centers. On the disbursing side, cash centers of the commercial banks withdraw new and fit banknotes according to their demand. Of the BOT’s 11 banknote management centers, there are 6 newly built centers, the head office and 4 pre-existing regional offices. As a result of the new banknote circulation scheme, PTO’s are no longer part of the banknote supply chain. This conforms to the shift in strategy of the Thai government to turn
In this section, we provide the background and further descriptions of the three problems in banknote planning. First, we describe the flows of banknotes at the national level. Then, we explain the demand forecasting problem. Subsequently, the descriptions for the banknote distribution planning problem and the banknote production planning problem are presented, respectively.

Under the new banknote circulation scheme, each commercial bank withdraws new and fit banknotes, according the demand they are face, from the central bank. Those banknotes are distributed to the public through ATM’s and counters at the commercial banks’ branches. In the reverse direction, some of the banknotes in circulation are deposited to the commercial banks, which then sort them into fit and unfit. Unfit banknotes are deposited to the central bank at the banknote management centers for further inspection and, eventually, for destruction. Additionally, the central bank also allows the commercial banks to deposit excess fit banknotes, which are sometimes referred to as sealed banknotes. Initially, sealed banknotes can only be withdrawn by the commercial bank that deposited them. After one month, sealed banknotes that have not been withdrawn by the corresponding bank are converted to fit banknotes that can be withdrawn by any commercial banks.

To summarize, for each of the five denominations of Thai banknotes currently being issued, there are five types of banknotes. They are new, fit, unfit, unsorted and sealed banknotes. We formulated the banknote demand forecasting problem as the problem of forecasting the monthly demand for new banknotes, up to two years into the future. However, in forecasting the demand for new banknotes, the forecasting of demand for other types of banknotes is also necessary. One of the reasons is that banknotes are relatively substitutable products. Particularly, for the same denomination, new and fit banknotes are very much substitutable, except in a few cases such as Chinese New Year when customers specifically demand new banknotes. This is because both types of banknotes can be distributed through the ATM’s and counters at the banks’ branches. Sealed banknotes also play an important role. The more the commercial banks withdraw their own sealed banknotes, the less they will withdraw fit and new banknotes. Therefore, in forecasting the demand for new banknotes, we need to know amount of fit banknotes that will be available and the amount of sealed banknotes that will be withdrawn during each month in the forecasting horizon.

Banknote distribution to the banknote management centers can be viewed as a large optimization problem. Most of the banknote management centers are located some several hundred kilometers from the Note Printing Works. Furthermore, the transportation of banknotes involves many security personnel and is exposed to unique risks that require expensive preventive measures. In short, banknote distribution consists of high-cost activities that need to be done safely and efficiently. With these concerns in mind, we studied the trade-off between inventory-related costs and transportation costs. Using the available inventory and cost information, we determined the economic order quantities for replenishing each of the banknote distribution centers. These results, along with the forecasted demand for new banknotes at each
banknote management center, then lead to a distribution plan.

Understandably, the commercial banks demand very high customer service level from the central bank regarding their deposits and withdrawal of banknotes. Specifically, each banknote management center has to maintain sufficient stocks of banknotes during each business day, in order to ensure that the commercial banks and, ultimately, the public have access to their accounts when they want to. The long lead-time in procuring banknote papers from overseas puts a lot of pressure on the distribution planning problem and, as we shall discuss later, on the production planning problem. As aforementioned, the demands for fit and sealed banknotes affect the demand for new banknotes by the commercial banks. As a result, banknote distribution planning is to be done with special care. That is, we need to make sure that we achieve the right trade-off not only between the inventory-related costs and the transportation costs. But we also need to make certain that the risks of stock-outs are included in the trade-off consideration. In short, those risks need to be properly and efficiently managed.

Banknote production is a fascinating process. It involves three printing operations, an examination of printed sheets (banknote papers) and, finally, the finishing and packaging stage. The first printing operation is offset printing. This step creates the background images on both sides of the sheets. Next, these sheets of 28 or 35 banknotes are printed by the intaglio printing machines. Very high pressure, up to 30 tons, is applied on the sheets to make sure that inks stay on the surface of the banknote papers. Graphical results of this operation are the portraits of the king on each note on each printed sheet. Those sheets are then examined carefully. Defective sheets are sorted out and then processed in a different finishing and packaging procedure. Good sheets, which are the sheets that pass the examination, are brought to the numbering machines. After serial numbers are printed on each banknote on the sheets, the sheets are put through cutting and packaging machines, which turn them into nicely packed banknotes. Each pallet of finished banknotes consists of 500 packs (500,000 notes).

The entire production process for each batch of banknotes takes between two to three weeks. Much of the production lead-time is spent in vaults or strong rooms, waiting for the sheets to dry after the printing operations. High denomination banknotes, which are the 500 Baht and 1000 Baht, take a longer time to produce, since they require two stages of intaglio printing, on the back side and then on the front side of the sheets. It is widely agreed by banknote printers that the intaglio printing operation produces most of the waste, resulting from imperfect ink wiping just before the high pressure is applied to deposit the remaining ink onto banknote papers.

In the solving the production planning problem, we focused on using information on production lead-time and machine capacity/availability to determine a production plan. There are other valuable by-products of this production planning process. These additional results include planned requirements for materials such as papers, security inks and printing plates. Early and accurate knowledge of paper and security ink requirements is especially critical. The procurement process for banknote papers can take up to six months. Even though the Note Printing Works produces most of its inks, some special input materials, such as the optical variable inks (OVI), need to be imported. That procurement process takes several weeks. Another important by-product of the production planning process is the machine loading or machine utilization. This information helps managers determine which of their expensive equipment are underused and assists engineers in planning preventive maintenance. Once equipment utilizations are measured, their overall equipment efficiency can be analyzed and then improved.

In practice, external forces can affect demand forecasting, distribution planning and production planning. In particular, extraordinary events and new information need to be considered in the forecasting and planning processes. We partially manage these unavoidable issues by allowing the managers and analysts to modify the demand forecast and distribution plan before these results are used as inputs in the distribution planning and production planning processes, respectively.

In the next three sections, we formulate and present the principles used to solve the three forecasting and planning problems in banknote management.

3. The Demand Forecasting Problem

There are some interesting aspects of the demand forecasting problem for banknotes. First of all, the demand for new banknotes has strong correlation with the economic growth of the country. That is, the demand forecasting problem for banknote is highly dependent on another challenging forecasting problem, that of annual economic growth. In practice, we use economic forecast data from various sources to estimate the economic growth for use in our demand forecasting. Secondly, especially in Thailand and other eastern Asian countries, there is the seasonally high demand for new banknotes during the Chinese New Year period. Other seasonal peaks are the weeks before and during the international
New Year and the traditional Thai New Year (Songkran or water festival). The demand for new banknotes during those periods could double the average demand throughout the year. Other interesting aspects of our demand forecasting problem include the aforementioned relationships between demands for new and fit banknotes. The amount of fit banknotes available depends on the amount of banknotes received from the commercial banks and on the fit rate of those banknotes. By fit rate, we mean the percentage of received banknotes that are considered fit in the sorting process.

The forecasting techniques that have been used can be considered, to a certain extent, as tried and trusted. During the past few years, forecasted demand turned out to be sufficiently close to that of actual demand. As a result, we made only minor changes to the forecasting process. Normally, we begin by forecasting the banknotes to be disbursed to commercial banks during each month of the forecast horizon. This is the first step in forecasting the demand for new banknotes. This forecasting step involves regressions and using historical data. Specifically, we use regressions to determine the value of banknotes to be disbursed to commercial banks, based on the estimated economic growth, the value of banknotes in circulation, the consumer price index and a few other indicators. Historical data are then used to determine the amounts to be disbursed for each denomination, type of notes, time period (month) and banknote management center.

The second step in forecasting demand for new banknotes is the forecasting of banknotes to be received from commercial banks. This step mirrors the first one, except that now we also take into account the correlation between the amount of banknotes to be received and the amount of banknotes to be disbursed. That is, the results from the first forecasting step are inputs to the second forecasting step. This is intuitive and rather obvious if we consider the fact that banknotes are circulated. That is, disbursed banknotes are put into circulation and then, after some time in the public use, the central banks receive these banknotes through the commercial banks. The more banknotes are disbursed and put into circulation, the more banknotes will be received by the central bank. BOT’s data show that the amount and value of received banknotes are usually slightly lower than those of disbursed banknotes. This reflects the nation’s economic growth.

Demand for new banknotes is determined in the third, and final, step of demand forecasting. The central formula in forecasting demand for new banknotes is the following:

\[ N_t = \sigma \bar{D} + D_t - S_t - E_t - F_t, \]

where \( N_t \) is demand for new banknotes during the month, \( \sigma \) is safety stock (unit in months), as recommended by analysts and subject to BOT’s policy, \( \bar{D} \) is forecasted average monthly disbursement, \( D_t \) is the forecasted disbursement during the month, \( S_t \) is the initial stock for the month, \( E_t \) is the amount of excess fit notes received during the month, and \( F_t \) is the amount of fit banknotes obtained from sorting during the month.

The safety stock varies between 1.5 to 2.5 months. It is the central bank’s policy to maintain safety stock of around 2 months. Once demand for new banknotes is forecasted, the planning division will hold a series of meeting with related parties, such as the Notes Printing Works’ Production Department, the Banknote Management Department’s Service Division, to listen to their inputs. Additionally, other relevant information and events are considered. These are things that might affect the demand for banknotes, such as upcoming local and national elections, etc.

4. The Distribution Planning Problem

The distribution part of the banknote supply chain was changed dramatically during the transition to the new banknote circulation scheme. That, along with the introduction of BMS, leads to a completely new way of managing banknote inventory. In particular, daily and up-to-date inventory information is now available. Furthermore, the distribution of banknotes now involves 11 banknote management centers. There is another notable change in the banknote distribution. Specifically, transportation of new banknotes to the centers has been rearranged in order to improve the efficiency, security and transparency. (Confidential details are omitted here.)

The new problem of banknote distribution becomes one of managing the inventory of five banknote denominations at 11 banknote management centers. In this new setup, transportation costs are measurable with reasonable accuracy. Meanwhile, inventory-related costs can be partially estimated. One way to do that is by considering the production costs of banknote in order to determine the opportunity costs of capital, which accompany the inventory on hand. With such information, we can now apply fundamental theories and results from inventory control to manage the banknote distribution from the strong rooms of the Note Printing Works to the provincial distribution centers.
There are two parts in our solution approach to the distribution planning problem, one of economic order (or replenishment) quantity analysis and one of transportation planning. In the first part, we use available information on the inventory and transportation costs to determine the optimal number of pallets of banknotes to distribute to each of the provincial distribution centers. We use the following economic order quantity (EOQ) formula for that computation:

$$EOQ = \sqrt{\frac{2K\lambda}{H}},$$

where $EOQ$ is the economic order quantity for the center, $K$ is the setup cost per order, $\lambda$ is the demand for new banknotes per month, and $H$ is the inventory holding cost.

Components of the setup cost include actual transportation related costs. Meanwhile, to determine the inventory holding cost, we use data on the production costs of banknotes to estimate the opportunity costs of capital for banknotes in inventory at the banknote distribution centers.

The second part of the distribution planning problem is the actual transportation planning of new banknotes. Input data include monthly demand of new banknotes (by denomination, at each distribution center), results from the EOQ analysis and historical demand of banknotes at the centers. First, we determine how many shipments to plan for each of the months in the planning horizon. This is based on the monthly demand and the total number of shipments, as determined by the EQO analysis. The next step is to identify the distribution centers to receive new banknotes in each month of the planning horizon. We use a heuristic approach here, which is based on the demand at each banknote management center and on the intervals between shipments for the centers.

The next step is to summarize the amount of banknotes to be shipped each time. This is where we rely on the forecasted demand. Specifically, we use the forecasted demand and the shipment plan, resulting from the heuristics, to determine the amount to be shipped each time. Finally, we modify these amounts moderately to conform to the transportation constraints faced by our transportation provider. The final result is a distribution plan that is supposed to satisfy the demand, while maintaining the appropriate levels of banknote inventory at the banknote distribution centers.

Based on our preliminary results, the number of shipments seemed to be higher than the actual one. Upon further analysis, we found that, historically, we have been very conservative in maintaining the inventory levels of banknotes. That is, we normally maintained high levels of banknote inventory at our centers. There are reasons for that. First of all, to ensure the smooth and uninterrupted cash payment system in the country, the central bank needs to make certain that the public have access to their money when they need to. Furthermore, security is a major concern during banknote transportation. The less frequent we ship, the less risk we are exposed to. But the more meaningful questions are questions we can quantify, and thus managed, the risk exposure of banknote transportation? And how do we find the appropriate trade-off between inventory holding costs and the costs and risks related to banknote transportation? These questions are being investigated.

5. The Production Planning Problem

As aforementioned, the lead-time required to procure banknote papers from the overseas suppliers are long. It could take up to six months from the issuance of purchase request (P/R) to the receipt of the banknote papers from overseas. Each shipment of banknote papers needs to be sampled and thoroughly tested before the papers are entered into the production process. The production lead-times are between 2-3 weeks, depending on the denominations and their production requirements. Producing high-valued denominations, which are the 500-Baht and the 1000-Baht banknotes, takes longer time and creates more wastes.

There are other inputs to the banknote production process, such as plates and inks. There are two main types of plates, those for the offset printing process and those for the intaglio printing process. The offset printing plates are made of polymer while the intaglio printing plates are made of steel. Usually, these printing plates can be used more than one time by carefully refinishing their surfaces. On the other hand, there are several types of inks. Understandably, various inks are required to produce the differences in colors for all denominations. Some of the inks, such as optical variable ink (OVI), also serve security purposes. The Bank of Thailand produces its own plates and inks. There are only some minor issues regarding the quality and standards of these two non-paper inputs to the production process. Thus, we shall not discuss them much further.

The demand planning for these inputs to the production process is almost an automatic result of the production planning. Specifically, once the production plan for banknotes has been determined, the demand requirements for papers, plates and inks are realized through the bill of materials. With procurement, production and preparation
lead times for papers, inks and plates, we can then have the procurement, production and preparation plans for the papers, inks and plates, respectively.

There are interesting by-products of the production planning process, such as machine loading or utilization rate for the banknote production equipment. We have already mentioned a few immediate by-products of the production planning, which are the paper procurement plan, ink production plan and plate preparation plan. Another important result of our production planning process is the measurability of some key performance indicators. We have mentioned machine loading above. For each of the alternative production plans, we can also measure flow time, processing time, waiting time, delay etc., for each production batch, even before the production begins.

6. Conclusion

The significant changes during the past few years in Thailand’s banknote circulation scheme have increased the visibility of the banknote supply chain. More and up-to-date information regarding banknote inventory and the related transactions can be found much quicker and easier. Those changes have also redefined the problem of collaborative planning, forecasting and replenishment (CPFR) of banknotes. In solving the new problem, such newly available and real-time information regarding banknote stocks permit the applications of modern forecasting, inventory control and production planning techniques. This is a significant development by the Bank of Thailand regarding its overseeing of the banknote supply chain.

We formulated the planning and forecasting problems of banknotes as three interconnected problems: the forecasting problem, the distribution planning problem and the production planning problem. These problems can be solved using modern forecasting, inventory control and scheduling techniques. Furthermore, the solutions are satisfactory. Specifically, so far the solutions have been sufficiently close to our earlier practices and, thus, can be implemented without too much difficulty.

Economic data and statistics on the numbers of banknotes disbursed and received are the key inputs to the forecasting problem. Meanwhile, to solve the distribution planning problem, the demand forecasts and data on inventory and opportunity costs are necessary. Finally, the distribution plan, along with data on production lead times and machine availability, are inputs to the production planning problem. In our web-based software, users are allowed to modify inputs to each of the three problems in order to reflect any newly available information.

In forecasting demand for new banknotes, we first estimate the banknotes to be disbursed and received. Then we use the relations between different types of banknotes and data on our sorting operations to forecast the demand for new banknotes. As aforementioned, there are two major steps in the distribution planning process. First, we determine the most appropriate lot sizes and banknote shipping frequencies to all the distribution centers. Then, we use a heuristic algorithm to determine an appropriate distribution plan. Once the distribution planning process is completed, we use information on production lead-times and machine availability to determine a production plan. There are interesting by-products of the production planning process, such as machine utilization and demand requirements for inks, plates and paper. These requirements are important results. This is because banknote papers need to be imported and the procurement process usually takes several months.

References