ICIC Express Letters
Part B: Applications
Volume 7, Number 7, July 2016

ICIC International ©2016 ISSN 2185-2766
pp. 1583–1590

A NOVEL TIME-DELAY ALGORITHM OF MULTIPLE BANKNOTES SORTING EQUIPMENT BASED ON PRE-ALLOCATION STRATEGY

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Received December 2015; accepted March 2016

Abstract. *Aiming at the cooperative working of all banknotes sorting equipment in banknotes sorting stream line, a time-delay algorithm of the tied paper currency based on the pre-allocated strategy is put forward. Based on the multi-station configuration of the banknotes sorting stream line, the relationship between the time intervals to produce the tied paper currency collaboratively by the multi-devices the number of stations is deduced. Then the maximum number of stations according to the optimal matching is calculated based on the minimum time to produce the tied paper currency. The statistics results of the real-time data in a period of time on the daily processing capacity at a banknotes sorting stream line with fixed stations show that the proposed time-delay algorithm based on pre-allocation strategy can effectively improve the overall efficiency of the banknotes sorting stream line.*

Keywords: Banknotes sorting stream line, Multi-device cooperation, Time-delay algorithm, Pre-allocation strategy

1. **Introduction.** In recent years, the application of traditional financial instruments, such as the small and medium size paper currency sorting machine, the tying machine and the binding machine is very extensive. However, the cash sorting pattern has the following problems: (1) Multiple distribution phenomenon; (2) Sorting equipment has unbalanced quality and there is not a general standard to pick the damaged banknotes; (3) The banks' sorting abilities are insufficient; (4) The settlement of the sorting amount is not timely and opaque [1,2]. At present, the number of China's currency circulation has the overall upward trend, but banks carry out sorting, counting and picking out damaged banknotes by hand in a great measure. On the other hand, the efficient social sorting mode has not been formed. However, the social paper currency sorting business has been mature in many European countries, whose requirements are very high for the performance, function and safety of the equipment [3,4]. The banknotes sorting mode is no longer limited to the use of a single device, instead of using a variety of equipment to achieve high quality and efficient sorting. At the same time, the acquisition of paper currency serial number is one of the main tasks of sorting [5-9]. The socialization mode of the paper currency automatic sorting is an inevitable trend of the bank paper currency's sort, which can reduce the original scattered cash handling risk. Therefore, a banknote sorting stream line has become a new solution plan for the bank cash processing business escaping from the traditional business model. In the production procedure of the banknote sorting stream line, when the paper currency with the same quality has too large processing amount, a plurality of devices of the line throwing the tied paper currency will have to wait, which will result in the reduction of the processing efficiency. By adding a delay algorithm based on pre-allocation strategy, the influence of this kind of waiting will be reduced on the whole sorting stream line and the overall equipment efficiency

will be improved. The remainder of this paper is organized as follows. In Section 2, the working pattern of banknote sorting stream line is introduced. The time-delay algorithm of multiple banknotes sorting equipment based on pre-allocation strategy is discussed in detail in Section 3. The experiments and the analysis of the results are described in Section 4. The concluding remarks are presented in the last section.

2. **Working Pattern of Banknote Sorting Stream Line.** The banknotes sorting stream line adopts the configurable modular design of multi-station, multi sorting pattern and multi product distribution and packet mode. It is composed of sorting and tying integrated machine, automatic stamping machine, elevating and distribution mechanism, ATM arranging mechanism, bill-bind equipment, laminator, integrated control epigenous computer and thread marking machine. According to the site situation, the sorting quality requirements, daily processing capacity and the finished product packaging requirements, the personalization scheme is formulated, which can meet the maximum banknotes processing needs.

The configuration of a four station banknotes sorting stream line is shown in Figure 1, which is composed of four sorting and tying integrated machines to form one sorting equipment cluster. The sorted and tied paper currencies are stamped by the automatic stamp machine and transferred to the elevating and distribution mechanism. Then they are allocated to the conveyor belt of the stream line according to the quality of the tied paper currency based on the predefined allocation scheme at four delivery points (A, B, C, and D). The pipeline conveyor belts are divided into three layers, and the running direction of the adjacent two layers is opposite, which is shown by the arrows in Figure 1. The tied paper currencies are carried out the finished packet by the paper bundle and packet equipment at the end of the running direction.

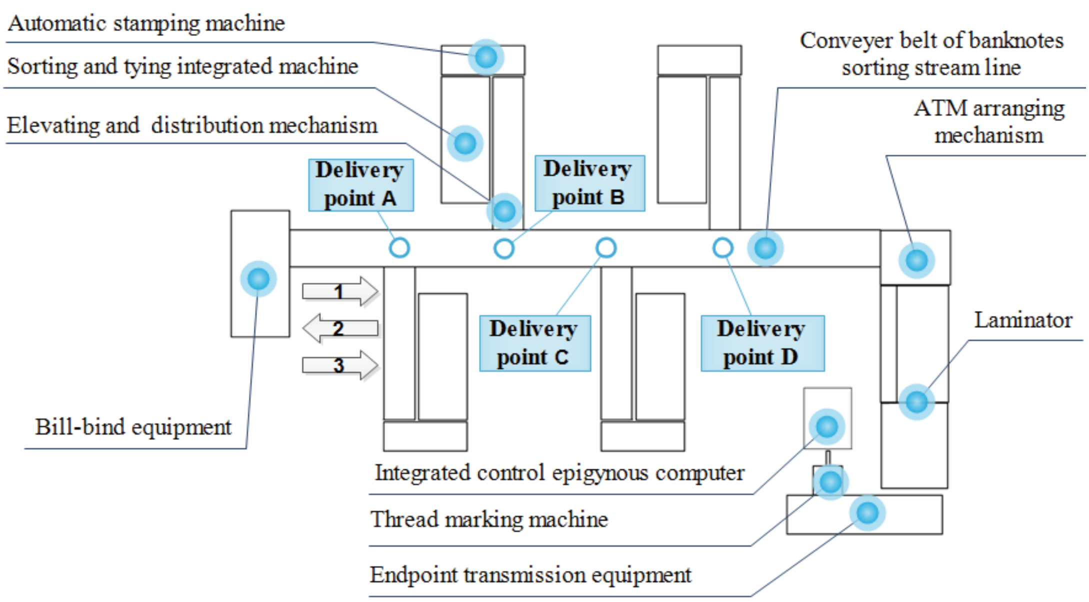

FIGURE 1. Equipment layout of banknotes sorting stream line

This scheme adopts the paper currency serial number identification and collection technology [5,6]. It carries out the information collection and storage of the paper currency serial number, equipment fault and operation condition by using the integrated control computer so as to provide query and statistical functions. The banknote sorting stream line adopts multi-device modular collaborative method to realize the on-line monitoring and fault detection of all equipment by the integrated control system and the real-time tracking of all the status of the devices and the positions of the tackled tied paper currency. The precision matching of the tied paper currency and the bundle paper currency by using position tracking at the finished product can achieve the two direction tracing based on paper currency serial number: bundle→tied→sheet and sheet→tied→bundle [7]. The clearing line is to make all kinds of devices work cooperatively. So when the tied paper currency is put into the stream line, it is not overlapped with the existing tied banknotes. At the same time, in order to reduce the failure rate of the receiving line, the separation distance between two tied paper currencies cannot be too small. In this way, the measurement devices are installed at the delivery point of each station, respectively located at the beginning and end of the delivery points to control the tied paper currency separation distance. This area is named as the launching area. When the launch area has not the waiting tied paper currency, the tied paper currency can be delivered. So the purpose of controlling the separation distance of two tied paper currencies is achieved.

By analyzing a lot of experiments results, although the paper currency quality fen into the inlet of each paper currency sorter is random, the general situation of the daily treatment has a certain law, which is shown in Table 1. The banknotes proportion with three qualities for 10 working days from the paper currency sorting center database in a bank is shown in Figure 2. It can be seen that the proportion of the damaged banknotes is rare and the currency in circulation accounted for more than 2/3. As a result of this processing proportion being not balanced, the phenomenon of currency in circulation concentrating in the cash sorting stream line often appeared. Therefore, when delivering the tied paper currency at the station located at the end of the stream line, at times there is too long time to wait for launching and even lead to the downtime waiting. These will have influence on the overall efficiency of the sorting. Therefore, if the system can be put into the overall control of the throwing time of the tied paper currency and the position of the rear end position in the delivery queue is pre-allocated, the waiting time of the rear processing equipment can be reduced and the sorting efficiency is improved.

Table 1. Proportion of daily processing capacity

	1	2	3	4	5	6	7	8	9	10
High quality currency	24%	18%	18%	10%	22%	30%	26%	28%	30%	21%
Currency in circulation	74%	80%	79%	88%	76%	66%	69%	68%	67%	75%
Damaged currency	2%	2%	3%	3%	2%	4%	5%	4%	4%	4%

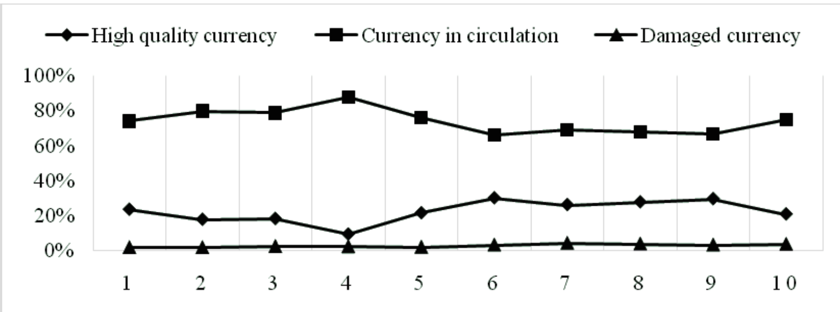

Figure 2. Proportion of daily processing capacity

3. **Time-delay Algorithm of Multiple Banknotes Sorting Equipment Based on Pre-allocation Strategy.** The symbol of the multiple banknotes sorting stream line is defined in Table 2.

After the deduction of multi-station scene, a case study of the system configuration of the two and three stations is carried out, which are shown in Figures 3-6.

A and B are the positions to deliver the tied paper currency for the two-station banknotes sorting stream, respectively. The conveyor belt moves from A to B at a fixed

Table 2. Symbol definition

Symbol	Definition
V	Working velocity of the conveyor belt
l	Minimum distance between two tied paper currencies
t	Time required by the tied paper currency moving l length at a speed of V
L	Minimum distance between two stations
N	Maximum finished tied paper currency amount per minute
n	The number of sorting stations of the current paper currency sorting stream line
$T_{\min}$	Minimum time of producing two tied paper currency with the same quality by sorting and tying integrated machine
$N_{\max}$	Maximum number of stations allowed to delay delivery for the current stream line
δ	The minimum time of the rear tied paper currency reaching the starting point again when the current tied paper currency arriving at the area of waiting for the deliverer
i	The count number from the current station to the last affected station
T_i	The deliverer time interval of the ith deliverer point from the starting point receiving the tied paper currency with the current quality
A	The first delivery point with same quality level
B	The second delivery point with same quality level
C	The third delivery point with same quality level
a_j	The jth tied paper currency at the delivery point A $(j = 1, 2, 3, \ldots, n)$
b_j	The jth tied paper currency at the delivery point B $(j = 1, 2, 3, \ldots, n)$
c_j	The jth tied paper currency at the delivery point C $(j = 1, 2, 3, \ldots, n)$
P	Ratio between the station capacity not affected by waiting deliverer and the station capacity affected by waiting deliverer

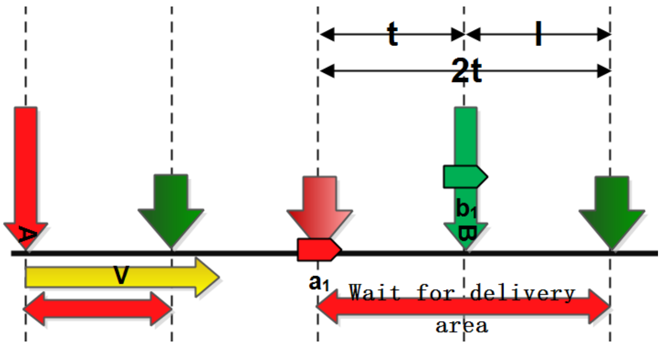

Figure 3. Deploying position diagram of two-station banknotes sorting stream line

velocity V. a_1 is a tied paper currency delivered by A, which has moved the starting position of the area for waiting for deliverer (red bidirectional arrow). At this point, a tied paper currency b_1 at station B will be put on the stream line and the length of the waiting for the throwing is $2l$. The maximum waiting time required to be the running state of the transmission line is $2t$. If you want to ensure the normal delivery of the tied paper currency in this delivery point, it is necessary to ensure that there is no tied paper currency arriving at the starting point of the waiting area when it will pass the waiting deliverer area. The tied banknotes deploying diagram of two-station banknotes sorting stream is shown in Figure 4.

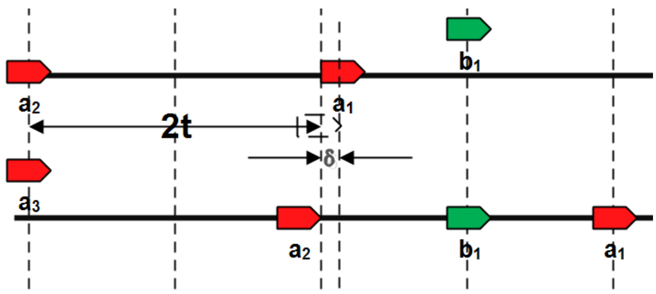

Figure 4. Tied banknotes deploying diagram of two-station banknotes sorting stream

Therefore, taking two stations as an example, the throwing time in station A should be more than $2t$. By doing so, when a_1 is triggered at the end of the waiting area, a_2 needs to be triggered by the δ time to trigger the starting point so as to set aside to wait for the opportunity to throw the tied paper currency at station B. Otherwise, if station A continuously releases the tied banknotes, station B will always be in the waiting state. At the same time, it can be concluded that the distance L between station A and station B should be at least greater than or equal to l so as to ensure that the tied paper currency can trigger the testing device at the starting point of station B when station A is in the delivery state. So the delay delivery time of the two stations is T_2.

$$T_2 = 2t + \delta \tag{1}$$

The deploying position diagram of three-station banknotes sorting stream line is shown in Figure 5.

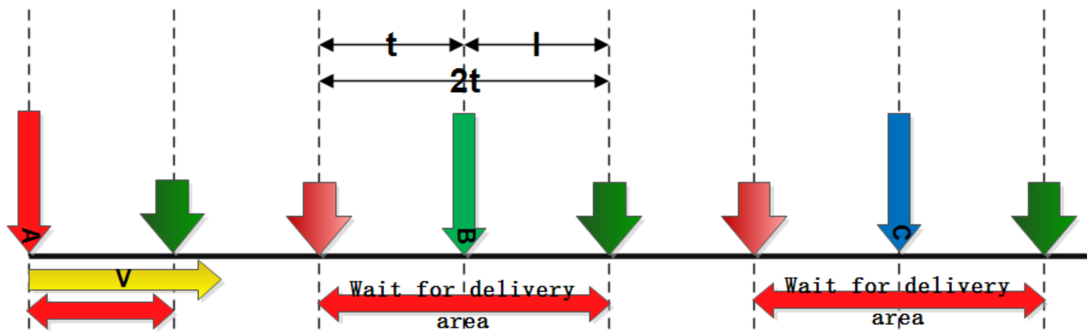

Figure 5. Deploying position diagram of three-station banknotes sorting stream line

Station A, B and C are the deploying positions of three-station banknotes sorting stream line, respectively, and other parameters are the same as two-station banknotes sorting stream line.

If station A and station B still adopt the deliverer mode as two-station banknotes sorting stream line, the deliverer of station A and station B is assured. However, if station A and station B alternately deliver the tied banknotes, at station C there will be possible a continuous queue at the waiting area of the currency. Station C will always wait for the A and B to put the money in the waiting area through the station C. It will seriously affect the timing of the station C, and even lead to station C stop waiting. It can be inferred that when the A and B are in the continuous delivery state, station C must be set aside time. So when station B has been successfully launched, the time interval that station A again put the tied banknotes must at least retain more than $2t$. Considering the distance between the thrown tied banknotes by station B and the previous thrown tied banknotes, the time interval of the continuous release of station A should be greater than $3t$. The process is shown in Figure 6.

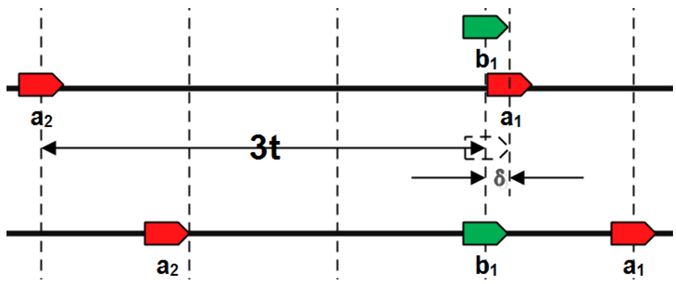

FIGURE 6. Deploying sequence diagram of tied paper currency in three-station banknotes sorting stream line

Seen from Figure 6, the time between b_1 and a_2 is greater than $2t$, that is to say $2t+\delta$. Then when b_1 reaches the end of the waiting launching area of station C and a_2 does not reach the starting point of the waiting launching area of station C, the time interval between a_1 and a_2 is $3t+\delta$ so that station C has the time to throw the tied paper currency. Thus the delay delivers time of the three station position T_3 and T_2 are defined as follows, respectively:

$$\begin{cases} T_3 = 3t + \delta \\ T_2 = 2t + \delta \end{cases} \tag{2}$$

In the same way, the delay thrown time of the four stations (T_4, T_3, and T_2) can be respectively deduced as:

$$\begin{cases} T_4 = 4t + \delta \\ T_3 = 3t + \delta \\ T_2 = 2t + \delta \end{cases} \tag{3}$$

To ensure that the rear stations of the banknotes sorting stream line have the time to keep the delivery, all work stations except the last station must allocate a certain time interval for a rear position when they throw the tied banknotes. The interval is proportional to the number of stations affected by this station. The following conditions can ensure that all stations have enough time to throw the tied banknotes.

$$T_i = it + \delta \quad (i = 1, 2, 3, \ldots, n) \tag{4}$$

The parameters of the adopted banknotes sorting stream line are described as follows. $l = 0.5m$, $N = 8$, thus the minimum deliver time interval $T_{\min} = 60/8 = 7.5s$, the transmission line running speed $V = 0.65m/s$, and $t = 1/V = 0.5/0.65 = 0.77s$. Seen form Equation (4), when t is a constant, the time interval of throwing the tied banknotes of stations T_i is proportional to the total number i of all stations from current station to the final station. Thus, when the number n increases, the minimum time interval T_i will increase accordingly. If $T_i \le T_{\min}$, there is no impact on the efficiency of the sorting equipment. If $T_i > T_{\min}$, the efficiency of the device will be reduced. Therefore, the maximum number of stations is n when $T_i = T_{\min}$. Set $i = n$, get into the Equation (4) to obtain:

$$n = \frac{T_n - \delta}{t} \tag{5}$$

When $T_n = T_{\min}$, the limit of δ is calculated to obtain:

$$N_{\max} = \lim_{\delta \to 0} \frac{T_{\min} - \delta}{t} \tag{6}$$

In order to obtain the upper bound of the station number under the current parameters, $N_{\max} = 9$. $n \le 9$ can be used based on the delay delivery method to reduce the influence of the back end station by waiting for the delivery time. That is to say for the banknotes sorting stream line ($n \le 9$) the pre-allocation strategy is adopted to realize the optimization of time delay of multiple sorting equipment [10]. So the equation for calculating the delay time of each station is described as follows.

$$T_i = it + \delta \quad (i = 1, 2, 3, \ldots, n, n \leq 9) \tag{7}$$

For the paper currency sorting system, the influence of too large banknote processing amount with single quality (general circulation currency) on the system performance has been discussed in the paper for the first time. Through research on the business processing procedure in the paper currency processing equipment, the too long currency delivering wait time of the back-end processing equipment will reduce the processing efficiency of a single machine, thereby reducing the efficiency of the whole system. So the relationship between the pre-distribution delay algorithm and the quantity of working locations is derived and the range of system parameters is calculated, which provides a theoretical basis for performance optimization for the product configuration of paper currency processing system.

4. **Simulation Verification.** Simulation experiments are carried on a banknotes sorting stream line with three stations of a bank sorting center. To make the experiments results more intuitive, the contrast mode on banknotes sorting quantity is used to obtain a set of P value. The processing capacities of currency in circulation before and after optimization are listed in Table 3, Figure 7 and Figure 8.

Table 3. Processing capacity of currency in circulation before and after optimization

	1	2	3	4	5	6	7	8	9	10
P before optimization	1.28	2.32	1.86	1.19	1.44	1.33	1.27	1.36	1.23	1.13
Optimized P	1.01	1.01	1.02	1.01	1.03	1.02	1.03	1.03	1.04	1.02

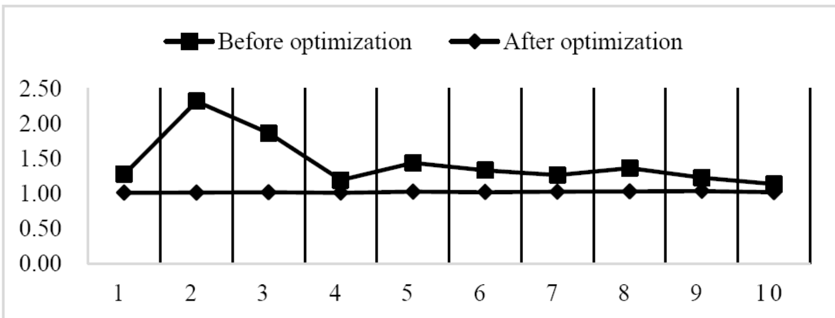

Figure 7. Processing capacity comparison before and after optimization

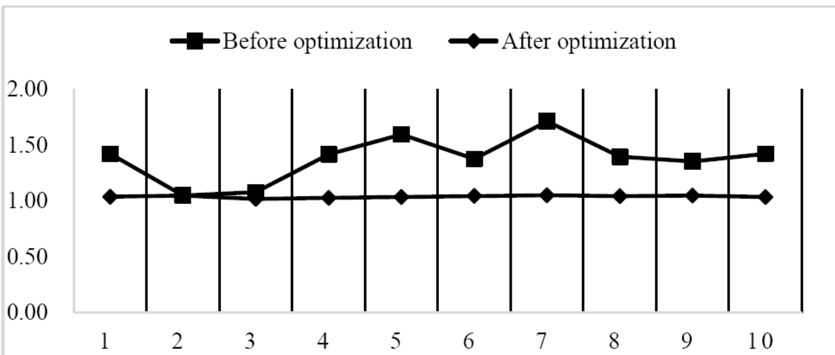

Figure 8. Processing capacity comparison of high quality currency

It can be seen from the above experiment results shown in Figure 7 and Figure 8 that in the number of banknotes sorting the value P is greater than 1. When the system is in the normal sorting state, for dealing with banknotes with same quality, the processing capacity without time delay will always be higher than the processing capacity affected by delay seriously.

5. **Conclusions and Future Work.** Through the derivation on the time-delay throwing algorithm of the tied paper currency in a banknotes sorting stream line, a time-delay pre-allocation strategy is proposed to make multi-stations work in the collaboration pattern. Simulation results show that the impact by the waiting for the thrown time on the rear equipment is decreased. So the overall sorting operation efficiency is improved.

Acknowledgment. This work is partially supported by the National Key Technologies R & D Program of China (Grant No. 2014BAF05B01), the Program for Liaoning Excellent Talents in University (Grant No. LR2014008), the Project by Liaoning Provincial Natural Science Foundation of China (Grant No. 2014020177), the Program for Research Special Foundation of University of Science and Technology of Liaoning (Grant No. 2015TD04) and the Opening Project of National Financial Security and System Equipment Engineering Research Center (Grant No. USTLKEC201401).

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