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A Novel Modeling Design Method for Automated Storage and Retrieval System Based on Petri Nets*

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***Abstract* - In nowadays, the materials handling level of a manufacturing enterprise reflects its whole production status. Driven by fierce global competition, a widely used logistics solution is to adopt auto warehouse with Automated Storage and Retrieval System (AS/RS). This paper develops a novel modeling design method for AS/RS which can clearly denote its status, simulate its real time behaviors and easily design its control operations. This paper is distinguished by one key contribution, which introduces the concepts of resource, color, time and signal to the Petri Nets modeling technology for the description of various logistic movements and the sequence, subsequent, conflict relations among them in AS/RS. Moreover the model can be decomposed and reduced convenient for analysis and simulation. The other contribution of this work is that the Petri Net model is intuitively applied to design the PLC control software.**

Index Terms* - *Materials Handling System (MHS), Automated Storage and Retrieval System (AS/RS), Petri Nets (PNs), Programmable Logic controller (PLC), Ladder Diagram (LD).

I. Introduction

Nowadays to cope with fierce global competition and rapid market changes, auto warehouse with Automated Storage and Retrieval System (AS/RS) of Material Handling System (MHS) plays an important role in modern manufacturing enterprise for storing and retrieving products and parts[1][2]. A typical auto warehouse with AS/RS consists of multi aisles with storage racks on either side which serviced by stacker cranes for operating storage/retrieval of the parts and conveyors for incoming and outgoing unit-loads. Characterized by high accuracy and speed, this solution can effectively improve labor cost, material management, and system throughput. However, these benefits depend on the design of its control system software, that is the rationality and the rapidity will greatly influence the performance of the system implemented.

Many techniques have been proposed to model this kind of discrete event system for analysis, simulation and optimization. Most of them are based on Petri Nets (PNs) and deal with typical operational problems, for example [3] defining proper storage and retrieval sequencing policies to maximize the system throughput. Dotoli et al [4] [5] employ a common coloured timed Petri Net to model the system dynamic behaviour and apply management policies to solve scheduling problems. Another issue is concentrated on the control policies that determine the performance of AS/RS, for example, Benamar et al [6] present a general approach with two travel-time models and deduced model using PNs for stacker cranes travel time. Using Stochastic Colored Petri Nets (SCPNs), another method [7] focuses on analysis and evaluation performance by dividing a generic model. Although these studies acquire adequate success, the common drawback of them is that they are policies simulation oriented modeling methods and not adapted for the design of the control system software.

Stimulated by the fact that the movements of palletised goods in AS/RS are similar to the transitions of tokens in PNs, we bring forward a modeling method based on Signal Timed Colored Resource Petri Nets (STCRPNs) to describe various logistic movements and the sequence, subsequent, conflict relations between them in AS/RS. What's important, in addition to used in simulation applications, the model also can be applied to design the Programmable Logic controller (PLC) program of the control system.

The remainder of this paper is organized as follows: section 2 describes the auto ware house with AS/RS under study and its materials movements; in section 3, following a brief review of PNs theory, a PNs extension model including resource, color, time and signal is present for the AS/RS, that can be decomposed and reduced convenient for analysis and simulation; the design of the control system based on the model is outlined in section 4 followed by conclusions in section 5.

II. System Description

As shown in Fig. 1, a generic AS/RS includes stacker cranes (1,2), conveyors (1,2,…,16) and rail-guided vehicles (RGVs) or automated guided vehicles (AGVs). In the warehouse, each stacker crane is assigned to serve one dedicated aisle which has two rows of storage racks facing one another and commonly has one pickup station and one delivery station for incoming and outgoing unit-load. Fig. 1 shows the conveyors (3,8) and the conveyors(5,10) are pickup stations and delivery stations respectively. The input storage process is as follows: a piece of palletised goods is put on the entrance conveyor of the warehouse, then transported to its corresponding pickup station along a path determined by its destination, finally picked up by the stacker crane and transported its assigned rack location. For example, the rack location of the incoming unit is P (row =3, layer =2, line=5), its transportation route is R(Conveyor1, Conveyor2, Conveyor4, Conveyor6, Conveyor7, Conveyor8, Crane2). The

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output retrieval process is to take out the needed goods from the warehouse and transport them to their corresponding export conveyors. For example, the outgoing unit P (row =2, layer =3, line=6) should be carried to the production line buffer1, its route is R(Crane1, Conveyor5, Conveyor6, Conveyor7, Conveyor9, Conveyor11, Conveyor12, RGV). The remainder pallets of the output goods are transported to the empty pallet area for reuse by the conveyors (13,14,15,16) .

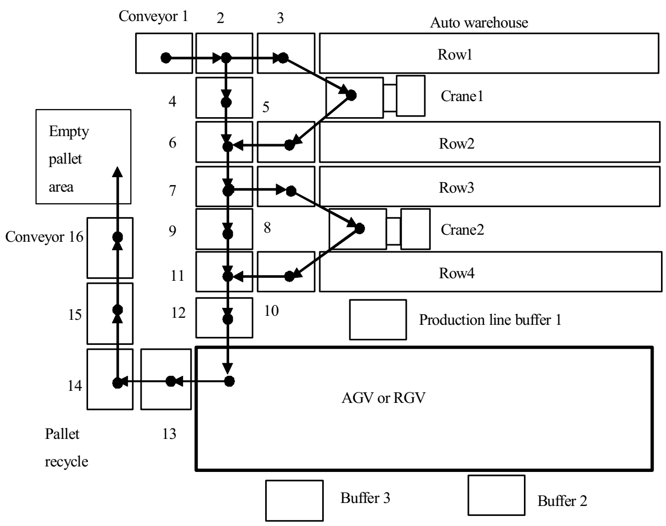

Fig. 1 A generic AS/RS plan layout of manufacturing enterprise.

III. THE STCRPN MODEL OF THE SYSTEM

Petri Nets (PNs) are originally developed by Carl Adam Petri [8] in 1962 and are recognized as being one of the most adequate and sound mathematics tool for description and analysis of synchronization, communication and resource sharing between concurrent processes. To well characterize the static structure and dynamic behaviors of a system, many PNs extension models have been proposed, such as high-level PNs and hierarchical PNs [7].We only review the basic concepts and notation used in this paper, more information about PNs can be taken from Refs.[9][10].

A. Review of PNs Theory

As a graphical tool, PNs use circles to denote places and use bars to model availability of resources, operation processes and transitions, represent the events, start, or termination of operations. Input and output places of a transition are places connected by incoming and outgoing arcs of the transition respectively. In order to simulate the dynamic behavior of a PNs, each place is marked with a nonnegative number of tokens.

Definition 1: A PN is a 5-tuple, $N=(P,T,I,O,M_0)$ where:

- $P=\{p_1, p_2, \ldots, p_m\}$ is a finite set of places, $m \geqslant 0$;
- $T=\{t_1, t_2, \ldots, t_n\}$ is a finite set of transitions, $n \geqslant 0$; $P \cup T \neq \Phi$, $P \cap T = \Phi$;
- I: $P \times T \rightarrow N$ is an input function so $I(p,t)$ is the weight of the arc directed from place to transition t;
- O: $T \times P \rightarrow N$ is an output function such that $O(t,p)$ is the weight of the arc directed from transition t to place p, where $IN=\{1,2,...\}$;
- M_0: $P \rightarrow N$ is the initial token of PN and $M(p_i)$ defines the state and tokens of the place p_i at a particular time, where $i = 1,2,\ldots,m$.

The behavior of a dynamic system can be described in terms of its state and changes. And a state or a token in a PN is changed according to the transition firing mechanism. When $M(p) \geqslant I(p,t)$, the transition t is enabled. The fire of an enabled transition result in a new token: $M'(p)=M(p)-I(p,t)+O(t,p)$.

B. Introduction resource to the PNs model

Due to the finiteness of the devices in an AS/RS, we adopt RPN (Resource Petri Net) to model the system: each device such as crane, conveyor, AGV, RGV and so on is represent as a finite resource place p; the goods on the device are expressed as the tokens in its resource place p, so M(p) denotes the number of the goods; the goods movement between two devices is described as a transition t, then the goods departing from the source device becomes the input function I and the goods coming to the destination device turns into the output function O. When the maximum amount of the resource place p Max(p) satisfies: $Max(p) \geqslant M(p)$, the transition t is resource enabled. To simplify the complexity of the system, we can reasonably assume that the maximum amount of each device is one piece of goods, i. e. $Max(p)=1$.

Definition 2: A PN $N=(P,T,I,O,M_0)$, if $I(p,t)=\{0,1\}$ and $O(t,p)=\{0,1\}$, then it is a generic Petri Net.

Definition 3: A PN $N=(P,T,I,O,M_0)$, if $t \in T$, $I(t) \cap O(t) = \Phi$ or $p \in P$, $I(p) \cap O(p) = \Phi$, then it is a pure Petri Net.

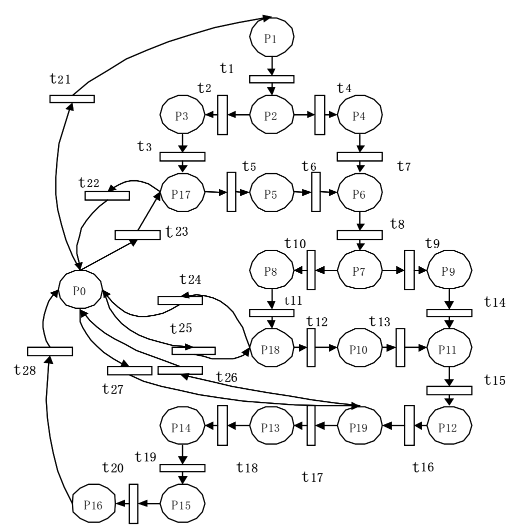

Fig. 2 The RPN model for AS/RS.

Because of the exclusively using of the devices in AS/RS, there is only one piece of goods handing over and taking over between two devices, both the input function I and the output function O are unique. The AS/RS shown in Fig. 1 can be modeled using a generic pure RPN (see Fig. 2), by which the sequence, subsequent, conflict relations among the logistic movements in AS/RS are clearly expressed. The description of all the elements in Fig. 2 is given in Table I. Owing to being a pure PN N=(P, T, I, O,M_0), the model can denoted by an incidence matrix :

$$A=[a_{ij}]_{n\times m} \qquad i\in\{1,2,...,n\}\ j\in\{1,2,...,m\} \tag{1}$$

where

$$a_{ij}=a_{ij}^{+}-a_{ij}^{-} \qquad p_j\in P \qquad t_i\in T$$

$$a_{ij}^{+}=\begin{cases}1 & if\,(t_i,p_j)\in O\\ 0 & otherwise\end{cases} \tag{2}$$

$$a_{ij}^{-}=\begin{cases}1 & if\,(p_j,t_i)\in I\\ 0 & otherwise\end{cases}$$

TABLE I
DESCRIPTION OF ELEMENTS

Elements	Interpretations
p_0	A virtual resource place with infinite capacity out of AS/RS, for example warehouse, production line buffer, empty pallet area…
$p_1,p_2,\ldots,p_{16}$	Conveyor1, Conveyor2, …, Conveyor16
p_{17},p_{18}	Crane1,Crane2
p_{19}	AVG
$t_1,t_2,t_4,t_5,t_6,t_7,t_8,t_9,t_{10},t_{13},t_{14},t_{15},t_{18},t_{19},t_{20}$	The movements of goods between conveyors
t_3,t_{11}:	A stacker crane pick up goods from a conveyor
t_5,t_{12}	A stacker crane unload goods to a conveyor
t_{16}	A AGV take out goods from Conveyor12
t_{17}	A AGV put empty pallet on Conveyor13
t_{22},t_{24}	A stacker crane store goods to warehouse (p_0)
t_{23},t_{25}	A stacker crane sort out goods from warehouse (p_0)
t_{21}	A piece of palletized goods from p_0 is put on the entrance Conveyor1
t_{26}	A AGV carry goods to production line buffer (p_0)
t_{27}	A AGV acquire empty pallet from (p_0)

Using the incidence matrix, we can analyze the structural property of the RPN model, for example deadlock and trap which are ever-present in a complex AS/RS. We can easily detect the deadlocks or traps in an AS/RS according the following determination rule [11] given by its incidence matrix:

Theorem 1: A subset of k places, P={$p_1,p_2,\ldots,p_k$}, in a Petri Net N is a deadlock (or trap) if and only if the addition of k column vectors of the sign incidence matrix of N, $A_1 \oplus A_2 \oplus \ldots A_k$, contains no + (or -) entries, where A_j denotes the column vector corresponding to place p_j, j= 1,2,… , k.

According to PN simplification principle, the RPN model can also be decomposed and reduced convenient for analysis and simulation. As shows in Fig. 3, the model is broken down into conveyor subnet PN_R、stacker crane subnet PN_S and AGV subnet PN_A by resource place category. From the simplified RPN model we can see that the total amount of the resource places is invariable, the transitions are divided into two types: transitions in subnet and transitions between subnet, both fire mechanism and fire conditions of transitions are unchanged, so the structural property of the original model is preserved.

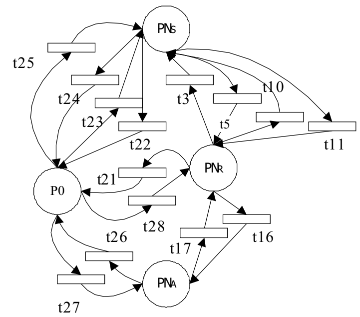

Fig. 3 The simplified RPN model for AS/RS

C. *Introduction color and time to the PNs model*

It is well known that deadlocks and traps in PN are cause by conflict relations who include two types: confluent relationship (Fig. 4a) and merging relationship (Fig. 4b). These two conflict relations in AS/RS register as sharing conjunct incoming device or outgoing device, which means there are restrictions between transitions. In order to solve the problem and avoid deadlocks and traps, we use high-level PN with color and time in modeling AS/RS.

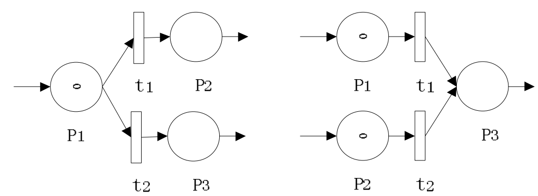

Fig. 4 (a) confluent relationship (b) merging relationship

Definition 4: A CRPN（Colored Resource Petri Net）is a 6-tuple, N=(P,T,I,O,M_0,C) where C is color sets of P and T

- $C(p_i)=\{a_{i1}, a_{i2}, \ldots, a_{im}\}$, i =1,2,…,m;
- $C(t_j)=\{b_{j1}, b_{j2}, \ldots, b_{jn}\}$, j =1,2,…,n;
- I：$C(p)\times C(t)\rightarrow N$ is an input function $I(a_{ih},b_{jk})$such that is the weight of the arc directed from place p_i ($C(p_i)=a_{ih}$)to transition t_j ($C(t_j)=b_{jk}$);
- O：$C(t)\times C(p)\rightarrow N$ is an output function $O(b_{jk},a_{ih})$ such that is the weight of the arc directed from transition t_j ($C(t_j)=b_{jk}$) to place p_i ($C(p_i)=a_{ih}$).

In the CRPN model, we endow tokens with corresponding colors Map(M,C) according to their destinations, then we can define these tokens to take part in corresponding color transitions and pass through corresponding color places. For example in Fig. 2, if we define $C(p_2)=\{a_1,a_2\}$, $C(t_2)=\{a_1\}$, $C(t_4)=\{a_2\}$, $C(p_7)=\{a_3,a_4\}$, $C(t_{10})=\{a_3\}$, $C(t_9)=\{a_4\}$, when the color of the token in place p2 is a1($Map(Mp_2,C)=a_1$), the transition t_2 ($C(t_2)=a_1$) is color enabled namely identity authorized, when $Map(Mp_2,C)=a_2$, the transition t_4 is color enabled. In this way, the confluent traffic problem of goods on conveyors (2,6) is settled.

Definition 5: A TCRPN（Timed Colored Resource Petri Net）is a 7-tuple, N=(P,T,I,O,M_0,C,D) where

- D={d_i, i =1,2,…,n }：P→N is time set of P and d_i is the delay time of place p_i which represent the needed time quantum from transition is fired to place reach its stable state.

The workable time of a token is equal to its natal time plus the delay time of its located place. If there are two input places both have tokens to fire transitions competing for one output place, the one with earlier workable time of token has priority of firing transition, which is First-In First-Out (FIFO) rule. For example in Fig. 2, if we define d4=3, d5=15, t4 and t5 are fired at the same time, i.e. the goods Token1 and Token2 are transported along Conveyor2→Conveyor4 and Crane1 → Conveyor5 respectively. Token1 arrived at Conveyor4 earlier than Token2 reach Conveyor5, and then the workable time of Token1 is earlier than that of Token2, therefore Token1 has priority to be used and t7 takes precedence of t5. In this wise, the merging traffic problem of goods on conveyors (4,5) is solved.

D. Introduction signal to the PNs model

In order to easily design PLC control algorithms, in our former work [12] using PN to model an AS/RS, we have applied two fontal concepts: events T and conditions I/O. Events are the system's operations, i.e. the goods movements on the devices of the AS/RS. Conditions are the system's states, i.e. the devices' status in the AS/RS. The occurrence of an event t needs some antecedent conditions and yields some subsequent conditions or states.

Signal Interpreted Petri Nets (SIPN) [13] are an extension of Condition Event Petri Nets that allow the handling of input and output signals. Klein et al [14] presented a graphical editor to design PLC programs using SIPN which can be automatically translated into Instruction List code according to the IEC 61131-3 standard. In this paper, one key difference from others' methods is the handling of signals: transitions (or events) are associated with firing conditions and results (I/O) which represent input sensors and output controllers in AS/RS respectively. Similar to [15], our goal is to control AS/RS by reading the input status from input sensors and sending updated status to the output controllers. The other key difference from others' methods is that such signal information is associated with time, colour and resource information in a Signal Timed Colored Resource Petri Nets (STCRPNs) to facilitate design, analysis and modification of PLC control programs using ladder diagram (LD).

Definition 6: A STCRPN is a 9-tuple, N=(P,T,I,O,M_0,C,D,X,Y) where

- X is a boolean function of input signals, which is evaluated after the transition has been found resource enabled (pre places of the transition marked and post places unmarked), color enabled and time enabled, then produce the immediate firing of the transition when they are true;
- Y is a physical output signal function that is executed by PLC control coded.

In STCRPNs, an immediate and simultaneous firing of all the transitions that can fire simultaneously takes place. Moreover, the firing process is iterated until no more transition can fire under this input setting. While in implementation by PLC program, these actions are orderly executed in scan round manner within a scan period. In each round, the input and output functions are evaluated and given out, then the transitions are executed. The details of the conversion from the STCRPN model to its corresponding PLC control program are given in the next section.

IV. Design Control System Based on STCRPN Model

A. Review of Design Methods based PNs for LD in PLC

Due to replacing the hard wired relay logics which were difficult to reuse, PLC has become the most common choice for industrial controls. Ladder Diagram (LD) is a graphical PLC programming language that uses software "device" to emulate the hardwired devices of the relay ladder logic scheme [16]. Although IEC (International Electro Technical Committee) has defined the well known standard IEC 61131-3 which suggests five languages for PLC programming: instruction list (IL), structure text (ST), function block diagram (FBD), sequential function chart (SFC), and finally LD, only LD is widely accepted and tested by engineers. In despite of its popularity and wide availability in automobile industries, LD is a low-level language which results in large and unwieldy programs. The overall design is experience-based, time-consuming and expensive, besides its verification is typically done through experiments or simulation. Therefore many industrial researchers have started to explore the possibilities of using Petri Nets tool as a modeling and analysis technique. Peng et al [17] presented a comprehensive survey on these methods, made a comparative analysis of PLC programming using LD and Petri Nets, and given a good explanation of transformation process. Another method [18] proposed a one-to-one mapping technique to efficiently convert Petri Nets model into PLC LD program for an agile and flexible manufacturing system. However it is still hard to find practical implementation in real universal industrial environment. The main problem of these methods is lack of unanimity. For a engineering compromise between efficiency and quality, we brought forward a novel mapping transformation method which is especially adapted for transformation from the STCRPN model of AS/RS to PLC LD program.

B. Transformation from STCRPN model to LD program

In this paper we adopt a kind of SIEMENS PLC S7-400 with STEP 7 programming tool [19] as an example which has been used in our practical applications. The software in STEP 7 is composed of program files (Organized Blocks OB and Functions FC), data files (Data Blocks DB and Memories M) and other interrelated files (such as mapping files, temporary variables, configuration files, and so on). More information about S7-400 can be taken from the literature [20]. The essential principle of our method is to convert the elements in the STCRPN model of AS/RS into the corresponding files in PLC program respectively:

Each place P in the model is mapped to a segment of data area. In our application, we create a DWORD (4 bytes, 32bits) structure on DB to denote a place P, for example DB100. DBD0 which is the data area from 0 to 3 byte in DB100 represents Conveyor1, DB100. DBD4 which is the data area from 4 to 7 byte DB100 represents Conveyor2 … The address of each data area uniquely marks every device resource in AS/RS. Furthermore the data information of the data area describes the information of color, time and goods token in the place, as shown in Table II. Like tokens are located in places of PNs, every goods token is represented by a WORD structure stored in the data area of its place. Then the movements of the goods between devices in AS/RS are expressed as the transfers of goods token words between data areas in PLC. The goods token number is unique and the goods token word is unchanged during its transfer process even if the PLC controller is out of power, which guarantees the veracity of the materials handling information.

TABLE II
STRUCTURE OF PLACE

Structure	Interpretations	Attribute
32-24bit	Transport Time	Time
23 bit	Finished flag	Color
22bit	Fault	
21bit	Overflow	
20bit	High/Low	
19bit	Loaded/Unloaded	
18bit	Motor Fast	
17bit	Motor Positive	
16bit	Motor Run/Stop	
15-12 bit	Goods Destination	Token (WORD)
11-0 bit	Goods Token No.	

TABLE III
PARAMETERS OF TRANSFER FUNCTION

Parameters	Type	Interpretations	Attribute
Dword0	DWORD	Sender	Place Token
Dword1	DWORD	Receiver	
Send	BOOL	Sending signal	Input condition
Received	BOOL	Received signal	
Time Base	BYTE	Time unit	Time
Slow Time	DWORD	Speed-down time	
Occupy0	BOOL	Sender has token	Output function
Occupy1	BOOL	Receiver has token	
Sent	BOOL	Sending flag	
Slow	BOOL	High or slow speed	

The transitions in the model are mapped to transfer functions FC which perform the transfers of goods token words between data areas. In the same way, conditions or signals in the model are converted to interrelated files in PLC. The conversion of transition is the key of the process. In the PN model, a transition links two resource places (pre and post place) using input arc and output arc. Similarly a transfer functions FC deals with two data areas (send and receive) according to input conditions and fire rules, and outputs control signals. Different types of transitions are mapped to different functions. For example, the parameters of a transfer function FC10 for conveyor system are shown in Table III. Its working process includes 4 steps: Firstly, the sender Dword0 and operate with the constant DW#16#8FFF, if the obtained result is nonzero, the sender has goods token, the output Occupy0 is set to be 1, the same as the receiver Dword1 and the output Occupy1. Secondly, if the sender has token and the receiver has no token, then the pass condition is satisfied and the token in the sender is written to the receiver. Thirdly, if both the sender and the receiver have the same goods token, which indicates the token is in transfer process, the output Sent is set to be 1. In the transfer process, whenever pass through a time unit, the Transport Time of the sender increases 1. If the Transport Time is greater than the setting time, the output Slow is set to be 1, the transfer motor decelerate. Finally, if the input Received is 1, then the transfer process is finished and the token in the sender is cleared.

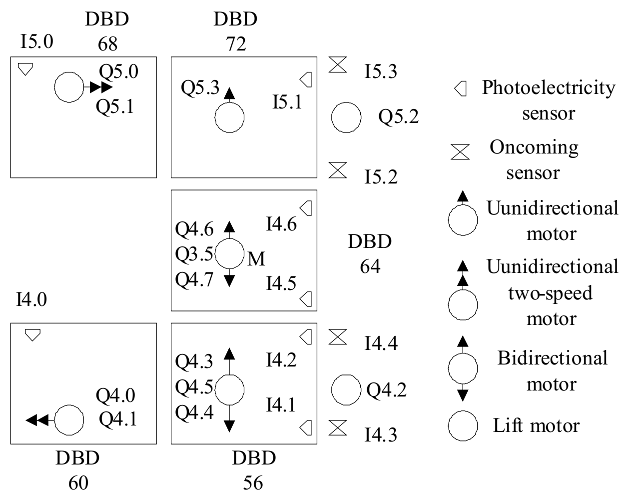

Fig. 5 The goods transportation in application

To illuminate the transformation method in detail, we make use of an example: a part of goods transportation in our application (See Fig.5). Its corresponding PN model is figured in Fig.6 and its mapped PLC LD program of transportation from the conveyor DBD64 to the conveyor DBD72 is shown in Fig.7. The mapping relationship is p3→DBD64, p4→DBD72, t3→FC10(DBD64→DBD72), X→I4.6, Y → {Q4.6, Q3.5, Q5.3}. If a piece of goods is located on the device DBD64 and its pallet covers the photoelectric sensor I4.6, and if there is no goods on the device DBD72 then the fire condition of the function F10 is satisfied and F10 acts: the goods token is transported from DBD64 to DBD72 and the output function L0.0, L0.1 and L0.2 are set to be 1 which drive the motors (Q3.5 and Q4.6) to run. Once the pallet of the goods covers the photoelectric sensor I5.1, F10 clears DBD64 which means the transportation process between DBD64 and DBD72 is finished. Here the output function L0.0, L0.1 and L0.2 are all 0 and the motors stop. From Fig.7 we can see the motors of the conveyor DBD64 run when a token is transported from DBD64 to DBD72 or from DBD56 to DBD64. In the implement of PLC LD program, only the last control loop of motor is valid in order to avoid confusions. So in addition to the input arc from DBD64 to DBD72, the function F10 also represents the output arc from DBD56 to DBD64.

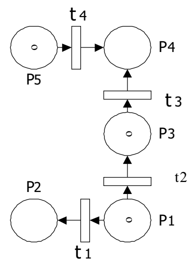

Fig. 6 The corresponding PN model

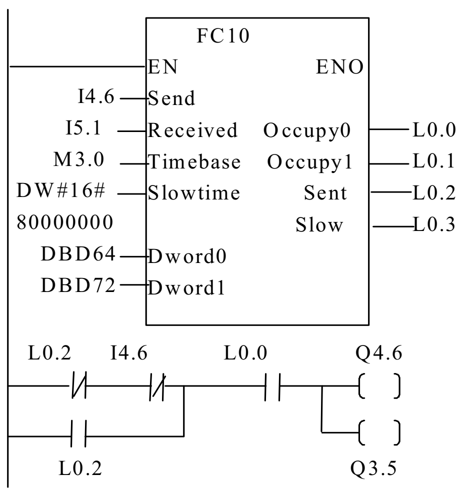

Fig. 7 The mapped PLC LD program

V. Conclusions

This paper presents a STCRPN for AS/RS modeling and its control system design. The proposed method has several distinct features including: firstly the model is general, intuitionistic, device-resource oriented and can represent any AS/RS; secondly the model can be simplified for analysis and simulation; finally the model can be easily mapped to PLC LD control program. In further research, we intend to introduce object-oriented design (OOD) technique to the model and make attempt to develop integrated control software development tools for auto generation of IEC 61131-3 codes with verification and use XML visualization technique to meet non-functional requirements which will be a aided tool for MHS to help the design and the implement of its control.

References

[1] Yaohua Wu, Ying Wang, Jiwei Xiao and Hongfeng Gao, "Research Status and Developing Trends of Modern Material Handing System", Chinese Journal of Mechanical Engineering, China Machine press, No. 4, 1999

[2] J.P. Van den Berg and A.J.R.M. Gademann,"Simulation study of an automated storage/retrieval system", International Journal of Production Research, Vol.38, No.6, pp. 1339-1356, 2000.

[3] S.C. Lin and H.P.B. Wang, "Modeling an Automated Storage and Retrieval System Using Petri Nets", International Journal of Production Research, Vo1.33, No.1, pp. 237-260, 1995.

[4] M. Dotoli, and M.P. Fanti, "Modeling of an AS/RS serviced by rail-guided vehicles with colored Petri nets: a control perspective", IEEE International Conference on Systems, Man and Cybernetics, Vol.3, pp.6, 2002.

[5] M. Dotoli, and M.P. Fanti, "Performance-based comparison of control policies for automated storage and retrieval systems modelled by coloured Petri nets" IEEE Conference on Emerging Technologies and Factory Automation, ETFA '03. Vol. 1, pp.299 – 306, Vol. 1, 2003.

[6] A. Benamar, Z. Sari, and N. Ghouali., "AS/RS Operation Models using Petri Nets", In Proceedings of the First National Workshop on Computer Science for Societies , pp.214-224,Blida, 2002.

[7] B. Abdelkrim, S. Zaki and G. Noureddine , "Performance analysis for multi-aisle automated storage/retrieval systems using visual Petri net developer" Proceedings of IEEE International Symposium on Computational Intelligence in Robotics and Automation, Vol.3, 003 pp. 1475 – 1481, 2003.

[8] C.A. Petri., "Kommunikation mit Automaten.", PhD thesis, Institut fur instrumentelle Mathematik, Bonn, 1962.

[9] T. Murata, "Petri Nets: Properties, Analysis and Applications", Proceedings of the IEEE, 77(4), pp. 541-580, April, 1989.

[10]Zhehui Wu, "Petri Net Introduction", China machine press, 2006.

[11]E.R. Boer, and T. Murata, "Generating basis siphons and traps of Petri nets using the sign incidence matrix", IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications, Vol.41, Issue 4, pp:266 – 271,April,1994

[12]Xiaowei Xu, "Controlling, Scheduling and Optimizing for Manufacture Enterprise Materials Handling System", Master thesis, Logistics Institute of University of Shandong, Jinan, December, 2001.

[13]G. Frey, "Design and formal Analysis of Petri Net based Logic Control Algorithms–Entwurf und formale Analyse Petrinetz-basierter Steuerungsalgorithmen", (ISBN 3-8322-0043-6), Dissertation, University of Kaiserslautern, Shaker Verlag, Aachen, April, 2002.

[14]S. Klein, G. Frey, and M. Minas, "PLC Programming with Signal Interpreted Petri Nets," in Proc. of the ICATPN 2003, Eindhoven, LNCS 2679, pp. 440-449, Springer Verlag, 2003.

[15]ShihSen Peng and MengChu Zhou, "Sensor-based Petri net modeling for PLC stage programming of discrete-event control design", IEEE International Conference on Robotics and Automation, ICRA '02. Vol. 2, 11-15 , pp.1907 – 1912, 2002.

[16]G. Michel, "Programmable Logic Controllers: Architectures and Application.", Chichester, U.K.: Wiley, 1990.

[17]ShihSen Peng and Meng Chu Zhou, "Ladder diagram and Petri-net-based discrete-event control design methods", IEEE Transactions on Systems, Man and Cybernetics, Part C, Vol. 34, Issue 4, Nov. pp. 523 – 531,2004.

[18]D. Thapa, S. Dangol and Gi-Nam Wang, "Transformation from Petri Nets Model to Programmable Logic Controller using One-to-One Mapping Technique", International Conference on Computational Intelligence for Modelling, Control and Automation, and International Conference on Intelligent Agents, Web Technologies and Internet Commerce (CIMCA-IAWTIC'05),Vol.2, pp. 228 – 233, 2005.

[19]SIEMENS A G. SIMATIC S7-Programming with STEP 7 V5. 1 Manual [M]. Berlin, SIEMES, 1998.

[20]SIEMENS A G. SIMATIC-System Software for S7-300/ 400 Standard and System Functions Reference Manual [M]. Berlin : SIEMENS, 1996.