AN APPROACH TO OBTAIN A PLC PROGRAM FROM A DEVS MODEL

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Abstract: Proposed in the paper is an approach to generate the PLC code from the Discrete Event System Specification (DEVS) model. DEVS have been widely accepted to model the real system for the discrete event system simulation. The objective of this paper is to generate PLC control code from the DEVS model. To achieve it, this paper proposes two steps. First step is to convert the real system into the virtual model using the 'three-phase-modeling procedure'. In the second step, the obtained model is formalized with DEVS formalism. The final model consists of different components, among them the State manager and the Flow controller model plays vital role to generate PLC code. In this paper, proposed steps are described with a work cell example.

1 INTRODUCTION

To survive and prosper in the modern manufacturing era, a manufacturing company should be capable of adapting reduced life cycle of products in a continuously changing market place. Simulation is a useful tool for manufacturers to adapt this kind of rapidly changing market to design and analyze complex systems that are difficult to model analytically or mathematically (Choi, 2000). Manufacturers who are using simulation can reduce time to reach stable state of automated manufacturing process by utilizing statistics, finding bottlenecks, pointing out scheduling error etc... For the simulation of manufacturing systems, manufacturers have been using various simulation languages, simulation software for example ARENA, AutoMod. Most of traditional simulation languages and softwares focus on the representation of independent entity flows between processes; their method is commonly referenced to as a transaction-oriented approach. In this paper, we propose an object-oriented approach that is based on the set of object classes capable of modeling a behavior of existing system components.

The object-oriented modeling (OOM) is a modeling paradigm, that uses real world objects for modeling and builds language independent design organized around those objects (Rumbaugh, 1991). Even though OOM has been widely known to be an effective method for modeling complicated software systems, very few researchers tried to apply the OOM to design and simulate manufacturing system software models. Based on the OOM paradigm, different researchers have proposed various modeling approaches despite the fact that they express them in different ways with different notations. For example, Choi et al. presented the JR-net framework for modeling which is based on the OOM paradigm of Rumbaugh et al., which is made of three sub-models(an object model, functional model, and dynamic model). Chen and Lu proposed an object-oriented modeling methodology to model production systems in terms of the Petri-nets, the entity relationship diagram (ERD) and the IDEF0 (Chen, 1994). Virtual factory (VF) is also very important concept to be considered in today's simulation environment. By using the OOM paradigm, VF concept can be implemented efficiently (Onosato, 1993).

Recently, Park (Park, 2005) proposed a 'three-phase-modeling framework' for creating a virtual model for an automated manufacturing system. This paper employs the three-phase-modeling framework of creating a virtual model, and the Discrete Event System Specification(DEVS) (Zeigler, 1984) for process modeling. The proposed virtual model consists of four types of objects. The virtual device model represents the static layout of devices. This can be decomposed into the shell and core, which

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encourages the reusability making possible to adapt different system configurations. For the fidelity of the virtual model, The Transfer handler model handles a set of device-level command that mimics the physical mechanism of a transfer. The Flow controller model decides the firable transfers based on decision variables that are determined by the State manager model. The State manager model and Flow controller model can be converted to PLC part. After finishing the process modeling by employing the three-phase-modeling framework, those two models will be the control information for the converting to PLC.

The overall structure of the paper is as follows. Section 2 represents the brief explanation about the PLC, and Section 3 is about the DEVS. The overall approach to create manufacturing system model for generation PLC code is described in Section 4. Section 5 gives as example cell, which is observed to find correlation between the PLC code and the DEVS model in Section 6. Finally, Conclusion and discussion is addressed in Section 7.

2 PROGRAMMABLE LOGIC CONTROLLER (PLC)

The Programmable Logic Controller (PLC) is an industrial computer used to control automated processes in manufacturing (Parr, 1999). PLC is designed for multiple inputs and outputs arrangements, it detects process state data through the sensing devices such as limit sensors, proximity sensors or signals from the robots executes logics in its memory and triggers the next command through the actuator such as motor, solenoid valve or command signal for the robots etc. PLC executes the control logic programmed in different types of languages. IEC published IEC 61131-3 to standardize PLC languages including Ladder diagram, Sequential Function Chart, Structured Text and Function Block Diagram (Maslar, 1996).

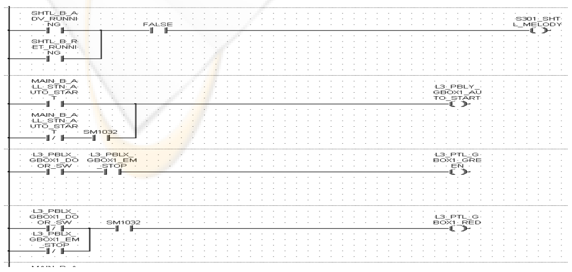


Figure 1: The PLC code in the form of Ladder diagram.

3 DISCRETE EVENT SYSTEM SPECIFICATION (DEVS)

DEVS formalism is introduced by Zeigler, which is a theoretic formalism and it supplies a means of modeling discrete event system in a modular, hierarchical way. With this DEVS formalism, we can perform modeling more easily and correctly by dividing large system into segment models and define the coupling between them. Formally, an atomic model **M** is specified by a 7-tuple:

$M = < X, S, Y, \delta_{int}, \delta_{ext}, \lambda, t_a >$

X : input events set;

S : sequential states set;

Y : output events set;

δ_{int} : $S \rightarrow S$: internal transition function;

δ_{ext}: $Q \times X \rightarrow S$: external transition function

$Q = \{ (s, e) | s \in S, 0 \leq e \leq t_a(s) \}$: total state of M;

λ : $S \text{->} Y$: output function;

t_a : $S \rightarrow Real$: time advance function:

The second form of the model, called a coupled model, indicates how to couple several element models together to form a new and bigger model. Formally, a coupled model **DN** is defined as:

DN = < X, Y, M, EIC, EOC, IC, SELECT >

X : input events set;

Y : output events set;

M: set of all component models in DEVS;

EIC $\in$ DN.IN x M.IN : external input coupling relation;

EOC $\in$ M.OUT x DN.OUT : external output coupling relation;

IC ∊ M.OUT x M.IN : internal coupling relation;

SELECT : 2^M - ø-> M : tie-breaking selector,

Where the extension .IN and .OUT represent the input ports set and the output ports set of each DEVS models.

4 APPROACH TO CREATE MANUFACTURING SYSTEM MODEL TO GENERATE PLC CODE

To construct the automated process, the factory designers have to consider the overall process layout. After deciding skeletal layout, the process cycle time is simulated by the discrete event system software like ARENA or AutoMod. In this stage, including the process cycle time and production capability, the physical validity and efficiency of co-working machines are also described. Simulation and modeling software QUEST or IGRIP are used for this purpose (Breuss, 2005).

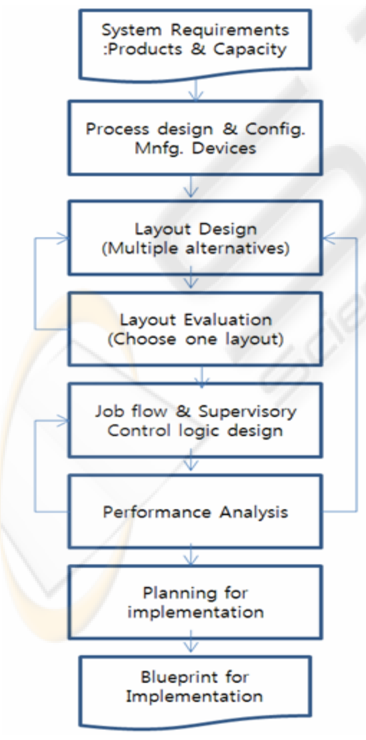

System Requirements :Products & Capacity
Process design & Config. Mnfg. Devices
Layout Design (Multiple alternatives)
Layout Evaluation (Choose one layout)
Job flow & Supervisory Control logic design
Performance Analysis
Planning for implementation
Blueprint for Implementation

Figure 2: Automated Factory construction procedure.

On the next step, the PLC code programming for logical functioning is done without utilizing information from previous discrete event systems modeling. The gap between the high level simulation of discrete event system and the low level physical process control logic need to be bridged for the utilization of process modeling and practical simulation in terms of physical automated device movement. This paper tries to find the bridge between these two different simulation levels and further describes automatic generation of PLC code from the DEVS model.

In developing the DEVS model, the first thing we have to do is to model the manufacturing system by the three-phase-modeling framework (Park, 2005). The framework describes manufacturing system modeling with 4 components; the Virtual device model, the Transfer handler model, the State manager model and the Flow controller model as shown in Figure 3.

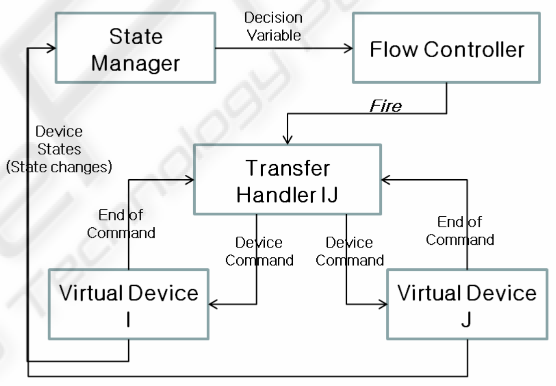


Figure 3: Outline of the virtual manufacturing model.

The Virtual device model shows the manufacturing devices. It has input port to receive the action signal and output port to send the work done signal. The Transfer handler model handles the parts stream and assisting resources (tools and pallets) between devices. This approach focused on the physical mechanism enabling the transfer than conventional approaches. In reality, a transfer happens by the combination of device-level command between co-working devices (giving and taking devices). The State manager model collects the state data of every device. Whenever there is a state change of devices, it will update the device states. Then, this information will be delivered to the Flow controller model as a decision variable. After getting the state information from the State manager model, the Flow controller model will decide firable transfer based on the system state (decision variables).

For the implementation of the virtual manufacturing system model, this paper employs the Discrete Event Systems Specification (DEVS) formalism, which supports the specification of discrete event models in a hierarchical modular manner. The formalism is highly compatible with OOM for simulation. Under the DEVS formalism, we need to specify two types of sub-models: (1) the atomic model, the basic models, from which larger ones are built and (2) the coupled model, how atomic models are related in a hierarchical manner.

When the DEVS model is developed, both the State manager atomic model for the process monitoring and the Flow controller atomic model for the actual control can be replaced the PLC part. Namely, control part for the manufacturing cell. Here is the goal of this paper.

5 DEVS MODELING OF A SIMPLE CELL BASED ON THE THREE-PHASE-MODELING FRAMEWORK

In this Chapter, we will observe a small work cell example. The work cell is modeled according to the three-phase-modeling framework and converted to the DEVS model like mentioned above. Finally, we will compare the DEVS model and the PLC code to find some meaningful bridge.

Figure 4 shows the small cell example. At first, an entity is generated from the Stack, which will lay on the AGV machine in P1, then AGV senses this raw part and moves to the P2 for machining. When machine detects the part arrival by the AGV, the machine starts to operate.

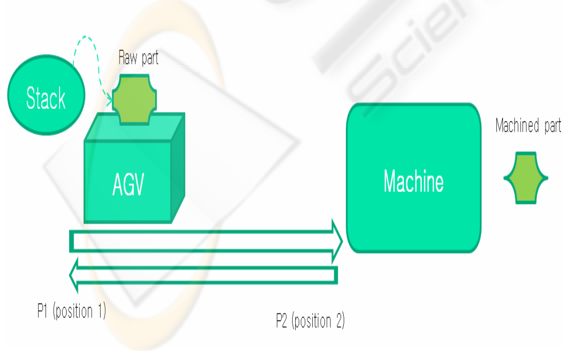


Figure 4: Example cell.

When we consider this example cell in terms of the three-phase-modeling framework, there are three virtual device models; the stack model, the AGV model and the machine model. The stack model generates the raw part entity and places it on the AGV for transfer. Until this point, the entity transfer process is between the stack and the AGV virtual device model as a result the transfer handler model is created between the stack the AGV model. Similarly, entity transferring between the AGV model and the Machine happens. This transfer handling model can be represented as *THam.* If there is any state change among the virtual devices, the changes are supposed to be reported to the State manager model. The State manager model maintains the decision variables in compliance with the reported state changes of the virtual devices and the Flow controller model will make a decision on firable transfer based on the decision variables. Figure 5 represents the constructed model about the example cell.

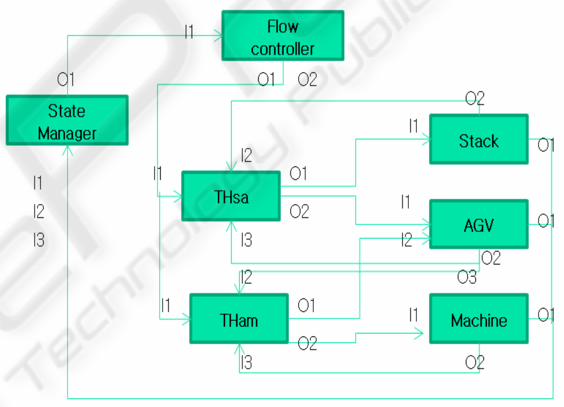
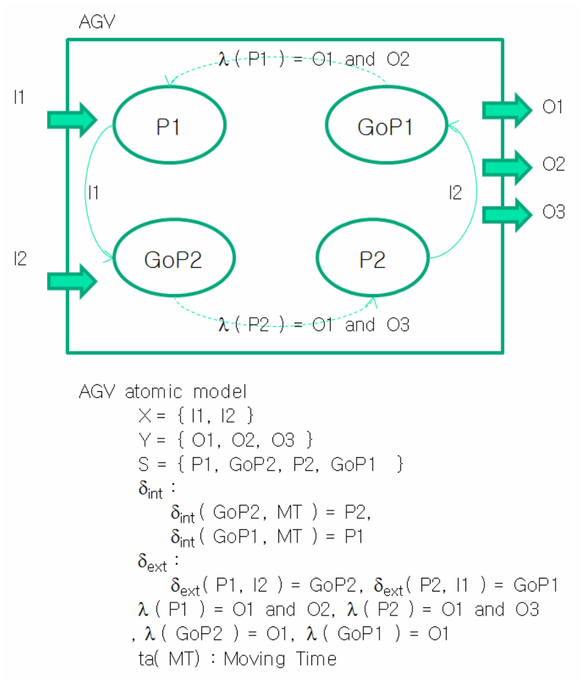


Figure 5: Modeling of the example cell in the Park's methodology.

Once the modeling by means of the three-phase-modeling framework is finished, second step is to convert the model to the DEVS formalism. In this example, every model is converted to the atomic model and entire cell will be the coupled model that is consist of all atomic models. Figure 6 is the converted DEVS model example of AGV. In the traditional implementation of discrete event system simulation using DEVS, DEVSIM++ is a simulation framework which realizes the DEVS formalism for modeling and related abstract simulator concepts for simulation, all in C++ (Kim, 1994). Through this open source frame, we can develop the discrete event system simulation engine easily. Once, both the DEVS implementation and the simulation with PLC control logic is done, we can achieve the overall physical control simulator for automated process.



AGV atomic model

$X = \{ I1, I2 \}$

$Y = \{ O1, O2, O3 \}$

$S = \{ P1, GoP2, P2, GoP1 \}$

δ_{int} :

$\delta_{int}(GoP2, MT) = P2,$

$\delta_{int}(GoP1, MT) = P1$

δ_{ext} :

$\delta_{ext}(P1, I2) = GoP2, \delta_{ext}(P2, I1) = GoP1$

$\lambda(P1) = O1$ and $O2$, $\lambda(P2) = O1$ and $O3$

, $\lambda(GoP2) = O1$, $\lambda(GoP1) = O1$

ta(MT) : Moving Time

Figure 6: DEVS model of the AGV.

6 CORRELATION BETWEEN THE PLC CODE AND THE DEVS MODELS

For the auto generation of PLC code from the DEVS model, we need to examine the PLC code of example cell and the DEVS models, especially the State manager and the Flow controller model.

In the manufacturing unit, PLC collects the process state information through the sensors. These sensor signals are referenced to decide next command or operation. This task is done by the state manager model in the modeled frame. The State manager model detects every change in state of the virtual device and then updates the decision variables. Similar to PLC code, the Flow controller model is supposed to have running logic that is kind of combination of decision variables. As a result, PLC code from the DEVS model can be divided into two parts. One part is for updating the decision variable from the signal of input port in the State manager model. Another is for actual logic composed of decision variables to fulfill the intended process control.

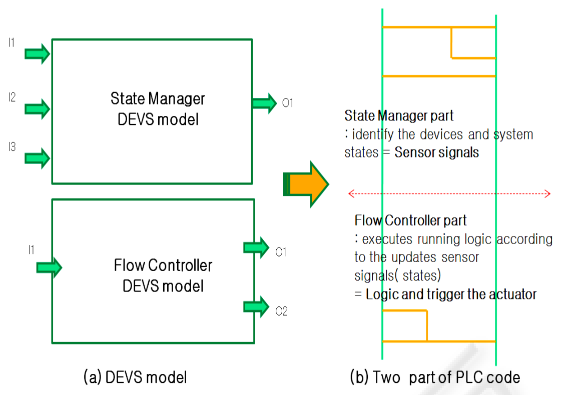

I1
I2
I3
State Manager DEVS model
O1
I1
Flow Controller DEVS model
O1
O2
State Manager part
: identify the devices and system states = Sensor signals
Flow Controller part
: executes running logic according to the updates sensor signals(states)
= Logic and trigger the actuator
(a) DEVS model
(b) Two part of PLC code

Figure 7: Two part of PLC code.

In the front part, the State manager model collects every state changes through the input port. The one input port of example cell has different kind of signal depend on the state. For example, the input port I2 is the signal from the AGV and it has 4 different kinds of state signals. With the same way, each input port of the State manager model has multiple input signals like shown in Table 1.

Table 1: The States of Atomic models.

	Atomic models	States	Input Signals
I1	Stack	Idle, Release	STACK_IDLE STACK_RELEASE
I2	AGV	P1 GoP2 P2 GoP1	AGV_P1 AGV_GOP2 AGV_P2 AGV_GOP2
I3	Machine	Idle Run	MACHINE_IDLE MACHINE_RUN

The memory structure in the PLC code can be classified into three groups. The first group is input memory which consists of input signal names and the second group is the output memory consisting output signal names and the last is the internal memory which is used to maintain the signal information of input or output and for temporary numerical calculation. The name of input signal can be determined with combination between the input port and its state name. In this way, we can give a name to all input signals.

As mentioned before, the flow controller model reads the decision variables to execute next command. Thus, we have to make decision variables representing the process state as the internal memory. As we did in the input variable for naming, we can give decision variables' name by putting the

'On' between the port name and the state name. Then, this decision variable shows the port's current state is active condition. Once decision variables are set, the Flow controller detects the firable output signals from the set variables. Figure 8 show the decision variables of each input of AGV model and moving condition. To the AGV, the possible condition to move from P1 to P2 is when the raw part is on the AGV, AGV's state is 'GoP2', and the machine state is 'Idle' at the same time.

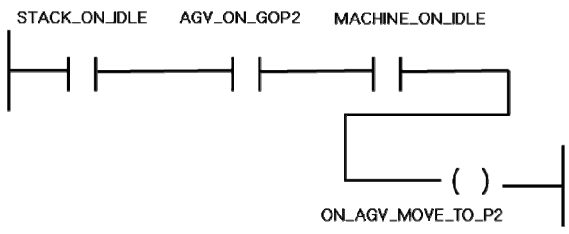
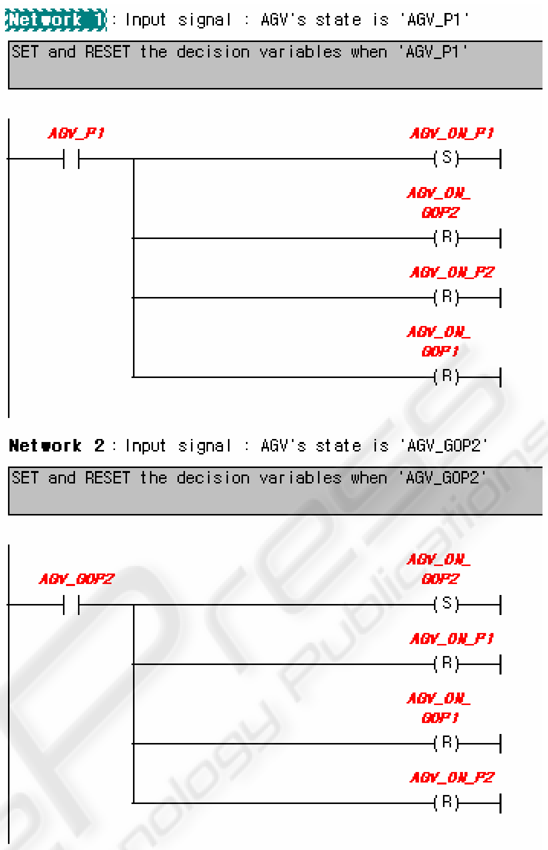


Figure 8: The triggering condition for AGV move.

As we have noticed for the case of the AGV model, the other devices' executing condition can be derived. While the PLC code for the State manager model part can be generated automatically with a combination of decision variables, the flow controller part is sometimes rather ambiguous. That is because unlike the flow controller, DEVS model is quite abstract and high level, the PLC part is very specific control area. Even though, process system designer can construct the DEVS model including low level of PLC, normally DEVS modeling is not fulfilled in this way. This aspect will be limitation or designer's choice in reference to PLC code auto generation. The DEVS modeling here is done specifically in mind of the PLC code generation of the Flow Controller model part. Figure 9 illustrates the two part of PLC code about the AGV from the State manager and the Flow controller model. And the Flow controller DEVS model for PLC code auto generation with the simple work cell is shown in Fig. 10.

7 DISSCUSSION AND CONCLUSIONS

This paper presents the PLC code auto generation methodology from the DEVS model. The PLC level control logic is rather closed and unopened engineering area while discrete event system modeling and simulation is widely used to

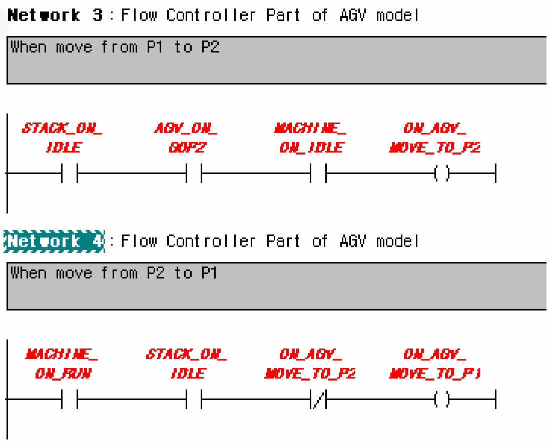

Network 1 : Input signal : AGV's state is 'AGV_P1'

SET and RESET the decision variables when 'AGV_P1'

Network 2 : Input signal : AGV's state is 'AGV_GOP2'

SET and RESET the decision variables when 'AGV_GOP2'

Figure 9(a): PLC code from the State Manager model of AGV model.


Network 3 : Flow Controller Part of AGV model

When move from P1 to P2

Network 4 : Flow Controller Part of AGV model

When move from P2 to P1

Figure 9(b): PLC code from the Flow Controller model of AGV model

measure the process capacity. By using the discrete event system simulation technique, the process or overall cycle time and throughput can be calculated.

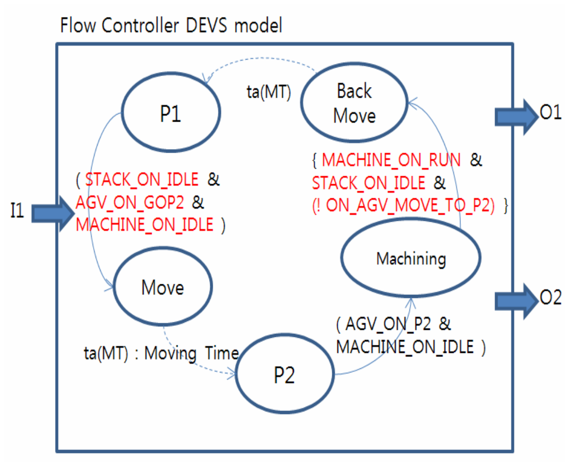


Figure 10: The Flow Controller DEVS model.

However, there is a big gap between the PLC code and the discrete event system simulation. This gap causes the repetition of process analysis work for the PLC programmer and the time delay to implement automated processing system in a manufacturing unit.

The overall procedure for proposed approach has three steps. Modeling the real system according to the three-phase-modeling framework is first step. And this model is converted to the DEVS formalism in second step. Among the 4 kind of models, the State manger and the Flow controller model is going to be replaced to the PLC part.

The generated PLC code from our approach can be categorized into two parts, one is from the state manager and another is from the flow controller. The first part is created from the input signals and the decision variable. And the latter part is from the control part which is from combination of decision variables.

The latter part generation is not achieved perfectly because the DEVS modeling level is more abstracted than the PLC level. However, this approach offers the overall framework for the PLC code generation from DEVS model. In the following future, the direction mentioned above will be the inevitable stream for the more physical process simulation, for the time saving toward the mass production condition and for better competitiveness to the company.

REFERENCES

B. K. Choi, B. H. Kim, 2000. Paper templates, In *Current Advances in Mechanical Design and Production Seventh Cairo University International MDP Conference*. New Trend in CIM: virtual manufacturing systems for next generation manufacturing.

J. Rumbaugh, M. Blaha, W. Premerlani. 1991. Paper templates, In *Prentice Hall Inc*. Object-Oriented Modeling and Design.

B. K. Choi, H. Kwan, T. Y. Park, 1996. Paper templates, In *The International journal of Flexible Manufacturing Systems*. Object-Oriendted graphical modelling of FMSs.

K. Y. Chen, S. S. Lu, 1997. Paper templates, In *International journal of Computer Integrated Manufacturing*. A Petri-net and entity-relationship diagram based object oriented design method for manufacturing systems control.

M. Onosato, K. Iwata, 1993. Paper templates, In *CIRP*. Development of a virtual manufacturing system by integrating product models and factory models.

Sang C. Park, 2005. Paper templates, In *Computers in Industry*. A methodology for creating a virtual model for a flexible manufacturing system.

B. P. Zeigler, 1984. Paper templates, In *Academic Press*. Multifacetted Modeling and Discrete Event Simulation.

E. A. Parr, 1999. *The book*, Programmable Controllers : An Engineer's Guide 3rd ed.

M. Maslar, 1996. Paper templates, In *IEEE Pulp and Paper Industry Technical Conference*. PLC standard programming language: IEC61131-3

F. Breuss, W. Roeger, 2005. Paper templates, In Journal of Policy Modeling. The SGP fiscal rule in the case of sluggish growth: Simulations with the QUEST

T. G. Kim, 1994. *The Book*. DEVS++ User's Manual