

# Chapter 35

## E-Catalogues of Equipment for Constructing an Injection Molding Digital Eco-Factory



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**Abstract** A digital eco-factory has been proposed by the authors for the simultaneous simulation of environmental performance, productivity and manufacturability. A virtual production line is constructed as a multi-agent system by connecting virtual equipment implemented as software agents which are automatically generated from equipment models. These models are provided as equipment e-catalogues. An e-catalogue of equipment includes a dynamic behavior model and a static property model of manufacturing equipment. In the previous papers, the above-mentioned concept was applied to constructions and usages of a digital eco-factory for PCA (Printed Circuit Assembly). In this paper, the above concept is applied to the construction of a digital eco-factory for injection molding. A production line consists mainly of an injection molding machine. An injection mold, a molding extraction robot, and a mold temperature controller are connected to the injection molding machine. The connection is not a sequential connection. Therefore, in the virtual injection molding line, more complicated interaction and control among equipment agents are

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required. Therefore, e-cataloging of equipment models for injection molding lines is more complicated. Trial implementation of e-catalogues for the above equipment has been executed for construction of a virtual injection molding line. On this virtual injection molding line, an environmental performance simulation in terms of electrical energy consumption simulation can be performed. Because this virtual line is structured by equipment agents which are generated from selected equipment e-catalogues, it can simulate environmental performance with various views such as from an equipment level, a production line level and a factory level.

**Keywords** Equipment modeling · Behavior modeling · Cyber physical production system · Virtual equipment · Multi agent system

## 35.1 Introduction

For a forecast of productivity and manufacturability, simulation systems have been used. As a simulation execution field, a virtual production line which is called a digital factory is constructed (Freedman 1999; Bley and Franke 2004). A digital factory involves the modelling of an actual factory (Kuehn 2006; Gregor et al. 2009). A virtual production line in the digital factory is constructed by virtual equipment which is a set of models of actual equipment on the actual production line. A virtual equipment can be implemented as software such as a software agent. A virtual production line can be constructed as a multi-agent system (Monostori et al. 2006). A digital factory is the basis of CPPS (Cyber-Physical Production System) (Monostori 2014).

A digital eco-factory has been proposed by the authors for a simulation of environmental performance in addition to productivity and manufacturability (Matsuda et al. 2012; Matsuda and Kimura 2012, 2013, 2015). A digital eco-factory is constructed as a multi-agent system. An environmental performance simulation strongly requires to model dynamic behavior of the equipment. On the other hand, it is difficult for users of a production simulation system such as a production system designer and an operator to write a software program of agents. Thus, it was proposed that a user constructs a virtual production line by selecting an adequate equipment model from a repository. These equipment models are called e-catalogue of equipment. A preliminary study for a PCA (Printed Circuit Assembly) line had been done, according to the above concept. E-catalogues of equipment are implemented and a trial construction of a virtual PCA line and simulations of electrical energy consumption has been executed (Matsuda et al. 2015, 2016).

The above concept is newly applied to the construction of a digital eco-factory for injection molding. The connection of equipment to construct a virtual line is not a sequential connection like a PCA. In the virtual injection molding line, more complicated interaction and control among equipment agents are required. Therefore, e-cataloging of equipment models for injection molding lines is more complicated. Trial implementation of e-catalogues for the above equipment has been executed for

construction of a virtual injection molding line. In this paper, this new application to injection molding is introduced.

## 35.2 A Digital Eco-Factory

### 35.2.1 Concept of a Digital Eco-Factory

Environmental performance of the planned production scenario can be examined in addition to productivity and manufacturability when the digital eco-factory is used. Simulation results on the digital eco-factory are used as references during production execution. There are three major use cases for the digital eco-factory as shown in Fig. 35.1 (Matsuda et al. 2015). The first use case is at the period of configuring the production line and/or the factory. In this use case, a configuration plan of a production line is determined and/or performances of newly introduced equipment is examined by constructing a virtual production line and simulation. The second use case is used determining a production plan. After process planning which is supported by the product design tool such as a CAD/CAM system, the production

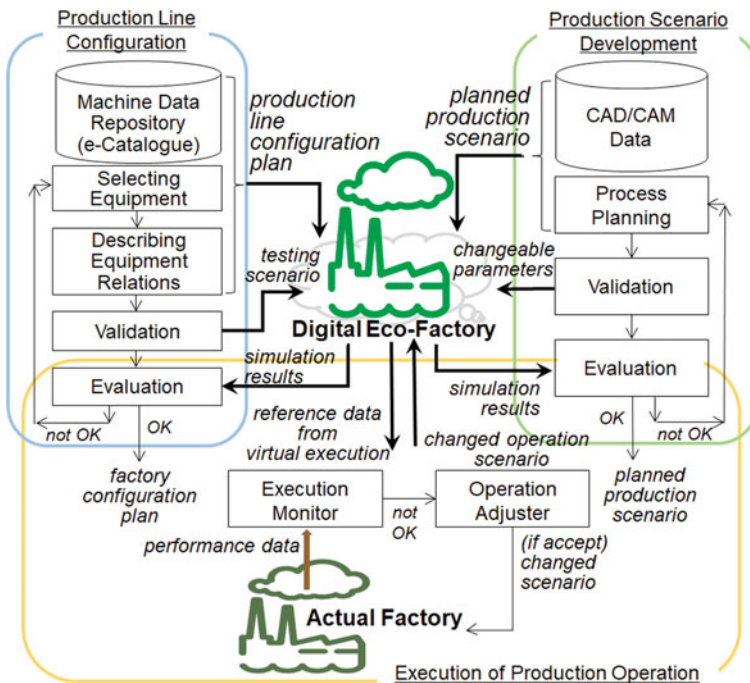


Fig. 35.1 Usages of a digital eco-factory

plan for the product is evaluated using simulation on the already constructed virtual production line. The evaluation is repeated by changing parameters and plans until satisfactory environmental efficiency and productivity data are obtained. The third use case is at the period of executing the production. In this use case, monitored data from the actual production line is compared with reference data from the digital eco-factory. If trouble is detected, a changed operation plan is generated and validated using a digital eco-factory.

### 35.2.2 Construction of a Digital Eco-Factory Using e-catalogues

To construct virtual production lines requires modeling an actual shop floor and its components, including their activities. Multi agent technologies are applied. All component equipment in the production line are configured as software agents. Figure 35.2 shows the procedure for the construction of a digital eco-factory. When using the digital eco-factory at first, a user constructs his/her own virtual production line on the computer. This constructing procedure starts from the step of selecting equipment models from e-catalogues, and a user provides configuration data which

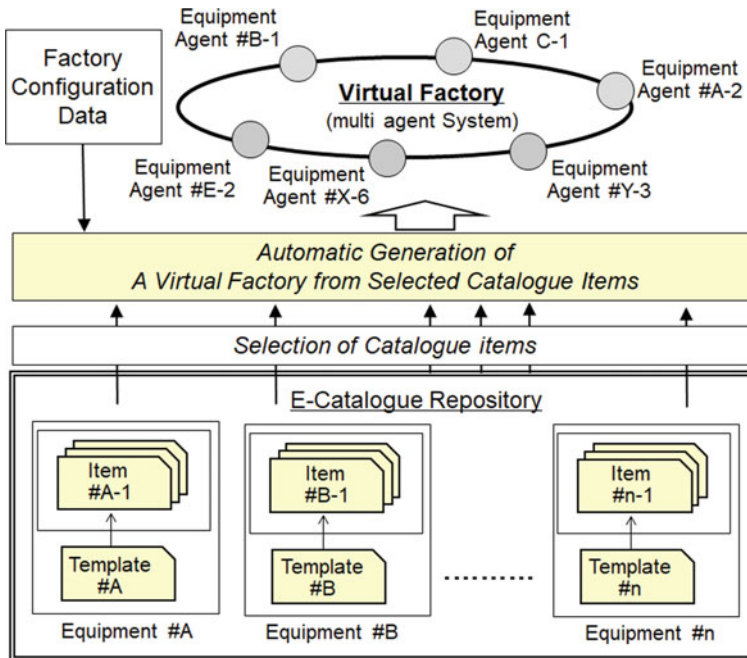


Fig. 35.2 Construction of a digital eco-factory

describe the connecting relationship between equipment, control policy and so on. Then, programs for machine agents and descriptions for the virtual production lines are generated automatically (Matsuda et al. 2016).

An e-catalogue of equipment is a group of one template and equipment items which are created using the template. The equipment template and/or equipment items are registered in a shared repository. An equipment template and an equipment item are required to include descriptions which specify properties, behavior resulting from equipment's activities, and communications with outside and/or other equipment. An equipment template is a schema representing a model for each equipment type including behavior. An equipment item is an instance of an equipment template filled with values. An equipment item is a model of a specific equipment. Template and item are implemented using a data description language such as XML or JSON.

## 35.3 Preliminary Study on Printed Circuit Assembly

### 35.3.1 *A Digital Eco-Factory for Printed Circuit Assembly*

A proposed multi-agent based construction of the digital eco-factory is applied to a PCA line and a trial digital eco-factory has been implemented as shown in Fig. 35.3. An e-catalogue creation system was prepared for supporting this trial. E-catalogues for a solder paste printer, an electronic part moulder and a reflow soldering oven were prepared using this system. When the simulation on the digital eco-factory is executed, input of a production scenario such as product data, schedule and operation data are required. These data affect the equipment behavior. The digital eco-factory for PCA is structured on a commercially available multi-agent simulator "artisoc" [13]. Figure 35.4 shows a screen shot of the simulation execution example using the generated virtual production of the PCA. In this example, there are two production lines. The graphs in the left column show conditions of line 1 and the right column shows conditions of line 2. The graphs in the second row show changes in the number of PCBs on the lines and change in the number of finished PCAs. The graphs in the third row shows changes in energy consumption of each machine. The graphs in the bottom row shows the total amount of energy consumption of each machine (Matsuda et al. 2015, 2016).

### 35.3.2 *Summary of Preliminary Study*

The trial digital eco-factory was used in a few industries as an experiment. As a result, the practical usefulness was confirmed especially about time qualitative changes of environmental performance. This trial shows how to construct the digital eco-factory with accuracy and high usability. This trial also shows prominent maneuverability at

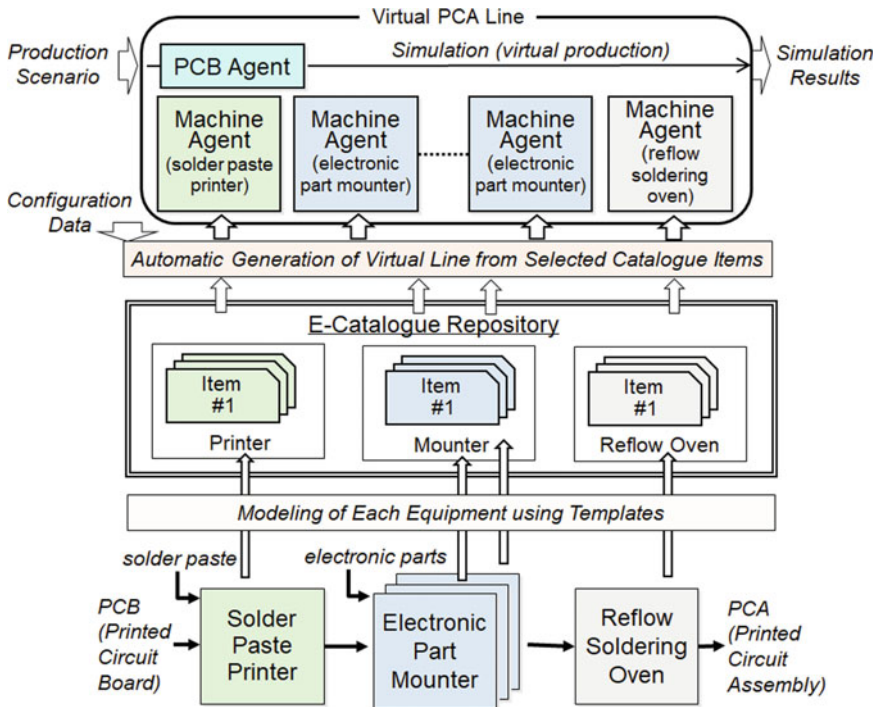


Fig. 35.3 Construction of a virtual PCA line

the usage stage. The user of this digital eco-factory can easily customize the configuration of the factory, target production scenario, granularity of simulation parameters, etc. This comes from modeling of each equipment including the performance simulation procedure which is equipment behavior. At this moment, an e-catalogue of a buffer had been introduced for more precise simulation of the virtual production (Matsumoto and Matsuda 2017).

This trial implementation on a PCA also shows how to make software agents of component equipment on the production line using an equipment model and how to construct a virtual production line as a multi-agent system. On a PCA line, interaction of equipment agents is simple. In other words, equipment agents are connected in sequence. The former positioned equipment finishes the job and then the next positioned equipment starts the job and finishes the job, and so on. However, in most of the production lines, there are more complicated interactions among equipment. Here is a requirement for the extension of an e-cataloging method.



Fig. 35.4 Example simulation using a virtual PCA line

## 35.4 Application on Injectin Molding

### 35.4.1 Modeling of an Injection Molding Line

The proposed concept for a digital eco-factory has been applied to injection molding. The structure of an injection molding line is shown in Fig. 35.5. An injection molding line consists of an injection molding machine, a molding extraction robot, a mold temperature controller and a mold. A mold is mounted on an injection molding machine. a mold temperature controller and a molding extraction robot are connected with an injection molding machine. An injection molding machine controls starting

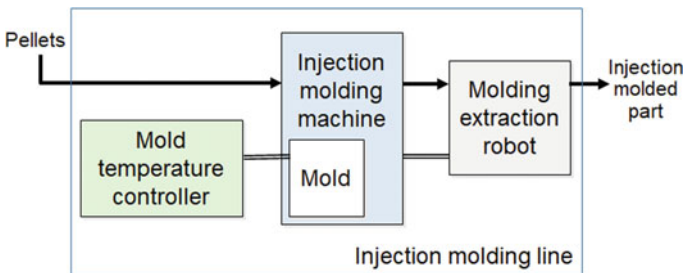


Fig. 35.5 Structure of an injection molding line

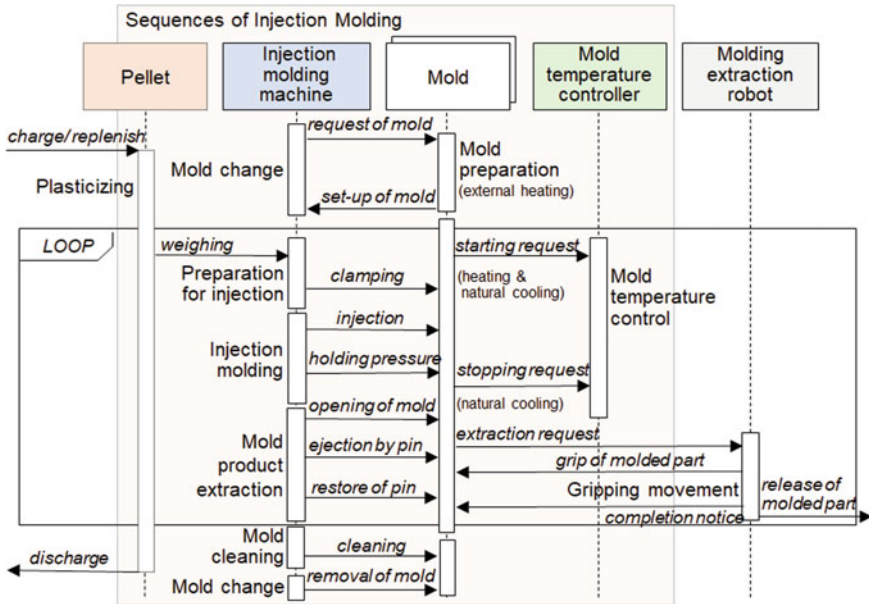


Fig. 35.6 Sequence in an injection molding line

and stopping the actions of a mold temperature controller and a molding extraction robot. Interactions of all equipment are shown in Fig. 35.6 which is a UML sequence diagram.

Sequence in an injection molding line is as follows. Pellets which are the raw material of the injection molded part are put into an injection molding machine, and are heated and melted. A mold is set on an injection molding machine. After these preparations, the injection molding process cycle starts. An injection molding machine requests the mold temperature controller to control the mold's temperature by heating or cooling. Melted pellets are weighed. A mold is clamped. An injection molding machine executes injection and holding pressure. An injection molding machine requests to stop the mold's temperature control. An injection molding machine makes an opening of mold, requests to a molding extraction robot to extract the molded part and ejects the molded parts by a set of pins. After extraction of the molded part by a robot, an injection molding machine restores the pins. The injection process returns to the start of the process cycle and repeats the process until the order is completed.



### 35.4.2 Virtualization of an Injection Molding Line

A virtual injection molding line is constructed as a multi-agent system as shown in Fig. 35.7. Component agents are an injection molding machine agent, a mold temperature controller agent, a molding extraction robot agent, a mold agent and a pellet agent. E-catalogues for an injection molding machine, a mold temperature controller and a molding extraction robot are prepared. An injection molding machine agent, a mold temperature controller agent and a molding extraction robot agent are generated corresponding to selected e-catalogue items by referring to operation data. Operation data includes the injection molding machine ID with a mold temperature controller ID and a molding extraction robot ID, a molded part ID, a number of the molded part, a mold ID, and so on. A mold agent is generated by referring to the operation data and the mold data. A pellet agent is generated according to the product data and the pellet data. The product data includes a type of a molded part, usable mold IDs, used pellet ID and so on. The pellet data include material, color, weight, required hopper temperature, required cylinder temperature, and required nozzle temperature.

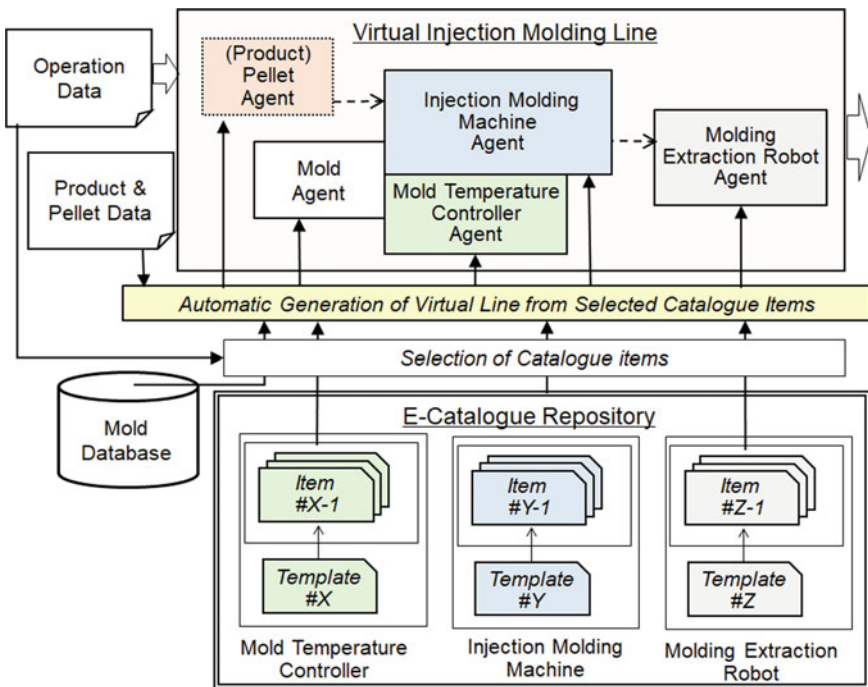


Fig. 35.7 Constructing a virtual injection molding line

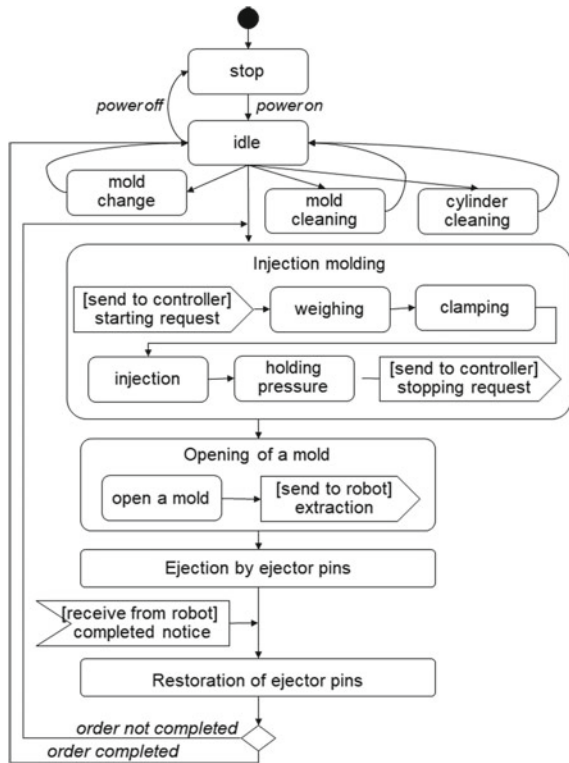
### 35.5 E-catalogues of Equipment for Injection Molding

#### 35.5.1 An Injection Molding Machine

The behavior of an injection molding machine is modeled as an activity flow shown in Fig. 35.8. When receiving an injection molding order in the idling state, the injection molding state starts. Before this, an adequate mold is prepared and changed. The injection molding process cycle is repeated until completion of the ordered amount. There are four processes in the process cycle: injection molding, opening of a mold, ejection by ejector pins and restoration of the ejector pins. At the beginning of injection molding process, the starting of the mold temperature control is requested.

At the end of the injection molding process, the stopping of the temperature control is requested for cooling of a mold. After cooling the mold, it is opened and a request to the molding extraction robot is sent out. Then the molded part is ejected by the ejector pins. After receiving acknowledgement of the completed extraction from the robot, the ejector pins are restored.

Fig. 35.8 Activity diagram for an injection molding machine



In the template for an injection molding machine, the abovementioned activity flows are described. The following parameters are described in the property part of the template. Properties are referred to by activity descriptions.

- machine ID
- associated mold temperature controller ID
- associated molding extraction robot ID
- action time (start-up, mold change, cleaning, weighing, clamping, etc.)
- electric energy consumption (start-up, cleaning, heating, weighing, ejecting, etc.)
- calculation formula for energy consumption (injection, holding pressure, cooling)
- calculation formula for cumulative energy consumption, etc.

A part of activity descriptions in the template for an injection molding machine using XML is shown in Fig. 35.9. The modelling of a specific equipment is to create the equipment item by filling up the template by value. Some values of parameter or variable in the calculation formula can be provided by operation data or product data.

```

<Equipment-Behavior-Catalogue>
  <equipment type="InjectionMoldingMachine">
    .....
    <activity>
      <status name="Injection"> ← start description of "Injection molding" behavior
      <source status="Idle"> ← previous state "Idle"
      <condition ope==">
        <arg> <param name="InjectionInstruction" ref="operation"/> </arg>
        <arg> <param name="@True" type="Boolean"/> </arg> </condition> </source>
      .....
      <pre>
        <dynamic name="CurrentStatus" ref="variables">
          <param name="@Injection" type="String"/> </dynamic>
        .....
        <dynamic name="CurrentPowerConsumption" ref="variables">
          <param name="PowerConsumption-Injection" ref="statics"/> </dynamic>
        .....
        <dynamic name="Send-StartingRequestToTemperatureController" ref="operation">
          <param name="@True" type="Boolean"/> </dynamic> </pre>
      <do>
        .....
        <dynamic name="CumulativePowerConsumption_kWh-Injection" ref="variables">
          <param name="CumulativeInjectionTime" ref="variables"/>
          <param name="CurrentPowerConsumption" ref="variables" ope="*"/>
          <param name="@3600" type="Decimal" ope="/"> </dynamic> </do>
      <post>
        <dynamic name="Send-StoppingRequestToTemperatureController" ref="operation">
          <param name="@True" type="Boolean"/> </dynamic>
        .....
        <dynamic name="InjectionInstruction" ref="operation">
          <param name="@False" type="Boolean"/> </dynamic> </post> </status>
      <status name="OpenMold"> ← start description of "Injection molding" behavior
      <source status="Injection">
        .....
    </activity> </equipment> </Equipment-Behavior-Catalogue>
  
```

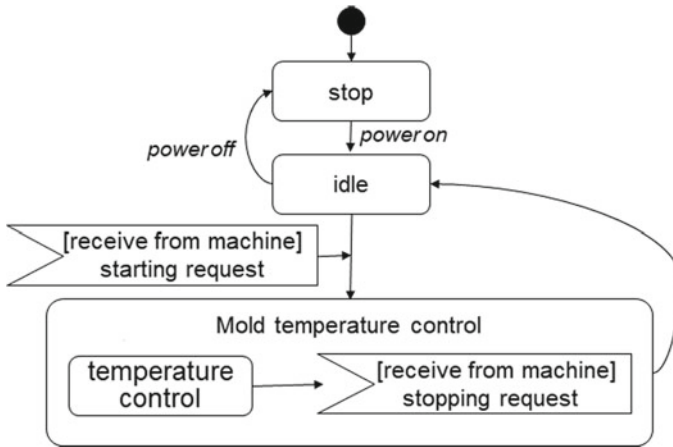
condition for starting

description for pre-processing

description for main processing

description for post processing

Fig. 35.9 A part of template for an injection molding machine described by XML



**Fig. 35.10** Activity diagram for a mold temperature controller

### 35.5.2 A Mold Temperature Controller

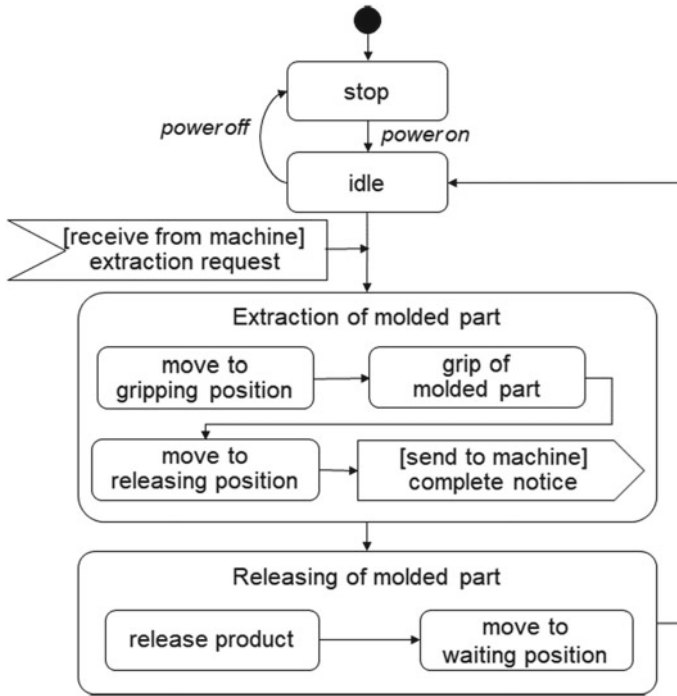
The behavior of a mold temperature controller is modeled as an activity flow shown in Fig. 35.10. When receiving the request for starting the temperature control from an injection molding machine, the controlling of the mold temperature for keeping the constant mold temperature is started. Constancy of mold temperature is kept by repeating heating and cooling/not heating. When receiving the request for stopping temperature control from an injection molding machine, the temperature controlling ends.

In the template for a mold temperature controller, the abovementioned activity flows are described. The following parameters are described in the property part of the template.

- controller ID
- action time (start-up, heating, etc.)
- heating capacity
- electric energy consumption (start-up, idling, heating)
- calculation formula for energy consumption (heat retention)
- calculation formula for cumulative energy consumption, etc.

### 35.5.3 A Molding Extraction Robot

The behavior of a molding extraction robot is modeled as an activity flow as shown in Fig. 35.11. When receiving the request for extraction of a molded part from an injection molding machine, the extraction process is started. To extract the molded part, a robot moves to the gripping position, grips the molded part, moves back to



**Fig. 35.11** Activity diagram for a molding extraction robot

the releasing position, and sends out a completion notice to an injection molding machine. At the releasing position, the runner is cut and the molded part is released. Finally, a molding extraction robot moves back to the waiting position.

In the template for a molding extraction robot, the abovementioned activity flows are described. The following parameters are described in the property part of the template.

- robot ID
- waiting position (x, y, z)
- action time (moving to gripping position, gripping of molded part, moving to releasing position, releasing of molded part, moving to waiting position)
- electric energy consumption (moving to gripping position, moving to releasing position, moving to waiting position)
- calculation formula for cumulative energy consumption, etc.

### 35.5.4 *Mold Data*

Mold data are prepared in a database not in an e-catalogue because a mold has no behavior. The following are described in the mold data.

- mold ID
- molded part ID
- mold size (length, width, height)
- capacity of cavity
- current temperature of mold
- mold set-up time
- pre-heating temperature
- pre-heating time
- cooling time, etc.

### 35.5.5 *Trial Experiment*

Trial implementation of the construction system of a digital eco-factory for injection molding is underway. The e-catalogue creation system is implemented in parallel.

In the e-catalogue creation system, the abovementioned equipment templates are installed already. An equipment item is created by filling up the parameters of the corresponding template with concrete values, calculation formula of electric energy consumption, etc. At the time when a virtual production line is constructed for simulation, some of parameters of the template are retained as variables. Their values are provided from production scenarios, operation data and/or product data. Equipment items in e-catalogues can be provided by equipment vendors, and also by production engineers using practical data from their factory.

A virtual injection molding line is constructed as a multi-agent system of equipment agents generated from the selected equipment items in the above e-catalogue. This virtual injection molding line is a core of the digital eco-factory for injection molding. Simulation using this digital eco-factory for injection molding will provide time series changes of electrical energy consumption from various views such as an equipment level, a production line level and a factory level. This trial digital eco-factory for injection molding is structured on a free multi-agent programmable modeling environment “NetLogo” [15]. Figure 35.12 shows a part of screen shot of the simulation execution example using the generated virtual injection molding line. Changes of electric energy consumption for the injection molding machine and the molding extraction robot are shown. This screen shot was taken when one process cycle finished.

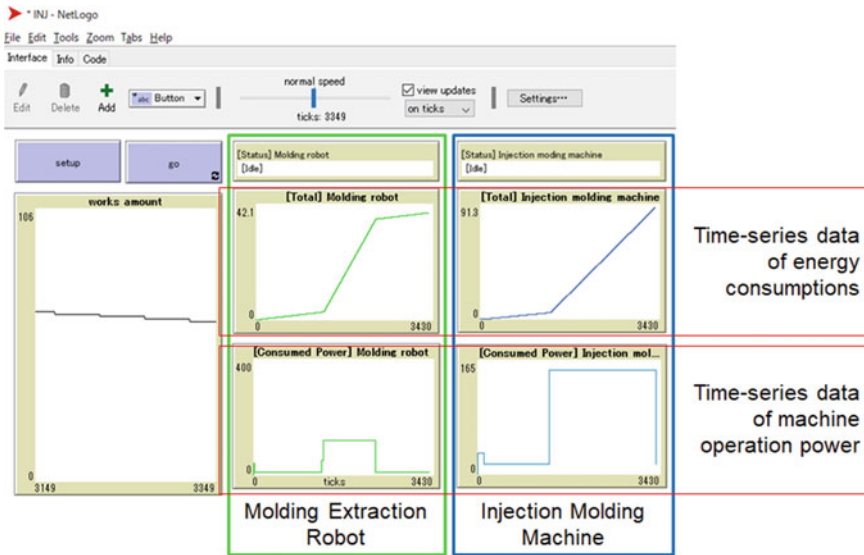


Fig. 35.12 Example display during the simulation

### 35.6 Conclusions

A virtual production line is a core of the digital eco factory. Environmental performance simulation on a virtual production system provides useful results for planning, operation and execution of sustainable manufacturing. The proposed virtual production line construction method using equipment catalogues has made possible a model-based construction.

A virtual production line is constructed as a multi-agent system. Its components are equipment agents which are derived from equipment catalogues. In other words, an equipment catalogue is a static description of an equipment model including its behavior. And an equipment agent is an executable model which is derived from the static description. As a result, a production line is modeled as a multi-agent system on which simulation is executable.

In this paper, the method for e-cataloging of equipment has been extended for constructing a digital eco-factory for injection molding with more complicated interactions among equipment. This extension indicates that the digital eco-factory with proposed e-cataloging method can be applied to more complicated production systems.

As a future work, by using implemented trial systems, experimental usage of a digital eco-factory is planned in industries. The result of the trial usage will show the feasibility of the proposed method and will lead to further practical developments in a digital eco-factory.

**Acknowledgements** The authors thank members of Technical Committee “DEcoF (Digital Eco Factory)” (2012. Oct.) by FAOP (FA Open Systems Promotion Forum) in MSTC (Manufacturing Science and Technology Center), Japan for fruitful discussions and their supports. Especially, the authors are thankful to Mr. Masayuki Kitajima for his great contributions. The authors are grateful to Dr. Udo Graefe, retired from the National Research Council of Canada for his helpful assistance with the writing of this paper in English. This work is supported by JSPS KAKENHI KIBAN (A) 18H03826.

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