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Virtual Design of Piston Production Line

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1. Introduction

Production paradigm has been changing since Henry Ford's ''we believe that no factory is large enough to make two kinds of products'' (Ford, H. 1926). With their Scion brand Toyota joined the race for offering customers an increasing product variety, a trend which has been characterizing the automotive industry throughout the last decades (Lee, H. et al., 2005). This development has been driven by two factors. On the outside demand, customization is driven by the improved competitive position of companies which address individual customer's needs (Kotler, P.1989). On the inside supply, customization strategies have been significantly promoted – if not was made possible at all-by advances in product design and manufacturing as well as information technology(Da Silveira,G.et al.,2001). Based on these advances it became possible to quickly respond to the customer orders by combining standardized modules and cut down the cost.

As the design of the production line is a complex and systematic project, many scholars advance to apply the computer-aided design to each unit of the production line design. Sang Hyeok Han et al (S.H. Han et al., 2011) used Maxscript in 3D Studio Max for automation of the visualization process, which has been applied to the production line of modular buildings with the output of lean, simulation, and visualization in the form of animation, to automate the visualization process as a post-simulation tool through sharing interactive information between simulation and visualization. Thomas Volling(Thomas Volling&Thomas S. Spengler.2011) provided a model and simulation of the order-driven planning policies in build-to-order automobile production, comprising separate interlinked quantitative models for order promising and master production scheduling and evaluating both models in a dynamic setting. Yong-Sik Kim (Yong-Sik Kim et al., 2006) proposed that virtual reality module uses a commercial virtual manufacturing system instead of expensive virtual reality equipments as the viewer of the immersive virtual reality system on a cluster of PCs and adopts the modified simulation algorithm. GAO Chonghui(GAO Chonhui et al.,2010) constructed the virtual simulation for automobile panels based on analyzing the motion characteristics of automatic press line and extracting the corresponding data of motion. These models took better advantage of computer-aided design technology for

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production line design, but these methods cannot model for the design process of the whole production line, and cannot complete dynamic analysis of production lines. Because of varieties and quantities of the piston are constantly changing, the above method is difficult to effectively and proactively verify the running condition of piston production lines.

As the part supplier of automobile assembly, piston companies also face the same problems, for example, Shandong Binzhou Bohai Piston Co., Ltd. has more than 70 piston production lines to manufacture those pistons such as car, motorcycle, marine, air compressors, chillers, engineering machinery and agricultural machinery pistons. Those size ranges from Φ30 mm to Φ350mm. However, due to the changing market and customized demand, the annual piston species is up to 800 kinds, some piston production line can change the product twice per month, some even more than five, and the production batch is ranging from small to mass. So it is difficult to quickly make the production planning under those demands with the traditional production line design methods. Therefore, it needs the advancing manufacturing technologies and methods to respond quickly to market changes and customized production.

As for production activities in production lines, it often faces the adjustment of design, and the well-designed production line can reduce operating and maintenance costs, improve equipment capacity factor and the efficiency of the system.

2. Design method of production line

2.1 Traditional design method of the production line

For traditional design method of the production line, it is necessary to provide such information as product type, production output, processes and other system properties to select processing equipments, logistics equipments and various auxiliary equipments, etc. And then, the layout of these devices need to take considerable combined with the structural characteristics of workshop space, and the space between the devices to ensure the maintenance of those devices and safely. The traditional design method includes: determining the cycle time through the layout of entire production; confirming the number of processing equipment with all the processes, synchronizing the processes, assigning the required number of operators, choosing logistics mode, designing the layout and drawing a standard plan charts, and so on. The traditional design method has those shortcomings as following(FAN Xiumin et al.2001; Shao Li et al.,2000):

1. Too complex and design results depending on the experts strongly.
2. Lack of dynamic characteristics description.
3. Not visually display.
4. Difficult to reflect the operational status of the various parts of the system early in the design;
5. Poor to predicate the bottleneck accuracy based on theoretical calculations and easy to waste the resources.

2.2 Virtual design of production line

Virtual design technology is a visualized design method of the production line to establish a visual modelling which can simulate a real production line in the virtual environment. It can

provide the model and analysis tool to rapidly design the piston production and improve the design rationality in the end(Shao Li et al.,2000).

Production lines involve multiple objects and actions with discrete, random, complexity, hierarchy and so on. Modelling for production lines is the foundation of virtual design. The traditional simulation model mainly focused on the design of algorithms that can be accepted by the computer, resulting in a variety of simulation algorithms and simulation software (Zhao Ji et al.,2000; S B.Yoo et al.,1994; H.T. Papadopolous& C. Heavey, J. Browne.,1993; Zhang Longxiang,2007). From the 1980s, due to high-level language for computer compiling, structured simulation modelling has been a great progress. Chan and Chan(F.T.S. Chan&H.K. Chan,2004) presented a review of discrete event simulation (DES) applications in scheduling for flexible manufacturing systems (FMS). Ashworth and Carley (M.J. Ashworth&K.M. Carley,2007) had conducted a review that addresses organizational theory and modelling using agent-based simulation (ABS) and system dynamics (SD).Shafer and Smunt(S.M. Shafer&T.L. Smunt,2004), Smith(J.S. Smith,2003), Baines and Harrison(T.S. Baines& D.K. Harrison,1999) targeted the larger domain of operations management and applied the simulation to it. However, most reviews limited themselves to either a single technique (DES or SD) or a single application area where more than one technique is used. However, because the interactivity of the structural simulation modelling is poor, it has not been widely application. With the developing object-oriented technology, object-oriented simulation modelling has been rapidly developed. Object-oriented modelling techniques (OMT) is a software environment applying classes, objects, inheritance, packages, collections, messaging, polymorphism and other concepts, which emphasizes the concept of the problem domain map directly to objects or the interface definition between objects, applies the modelling, analysis and maintenance of the realistic entity, so that the built model is easy to reflect the real objects, and makes the constructed model with re-configurability, reusability and maintainability. And it is easy to expand and upgrade and can reduce the complexity of systems analysis and development costs significantly. Many different OMT methods have been advanced, such as OMT / Rumbaugh, OSA / Embley, OOD / Booch et al (Zhang Longxiang,2007; Par Klingstam& Per Gullander ,1999; Dirk Rantzau et al.,1999).

But when these models are used for dynamic performance analysis on the production line, the modelling is more complex and difficult to describe the dynamic characteristics of the production line quickly and easily, which has greater limitations. QUEST is a virtual integrated development environment applied to queue simulation analysis in Deneb company, which is proper to simulate and analyse the accuracy of the technological process and productivity, in order to improve the design, reduce risk and cost, and make the planned production line meet the design requirements early in the design and implementation, before investing real facilities. Combining the advantages of the QUEST virtual simulation development environment and unified modelling language (UML), this paper presents the simulation, analysis and modelling methods of Virtual Design of Piston Production Line (VD-PPL) to analyse the static and dynamic characteristics of the piston production line.

3. Virtual design of Piston Production Line (PPL)

3.1 The frame of VD-PPL

Due to the characteristics such as multi-objectives optimization, strong resources correlation, large randomness etc., based on system theory and hierarchical design methodology, VD-

PPL theoretical model is divided into five levels: Support, Management, Transaction, Simulation and Decision level levels. Design features and contents about of all levels are shown in Figure 3.1.
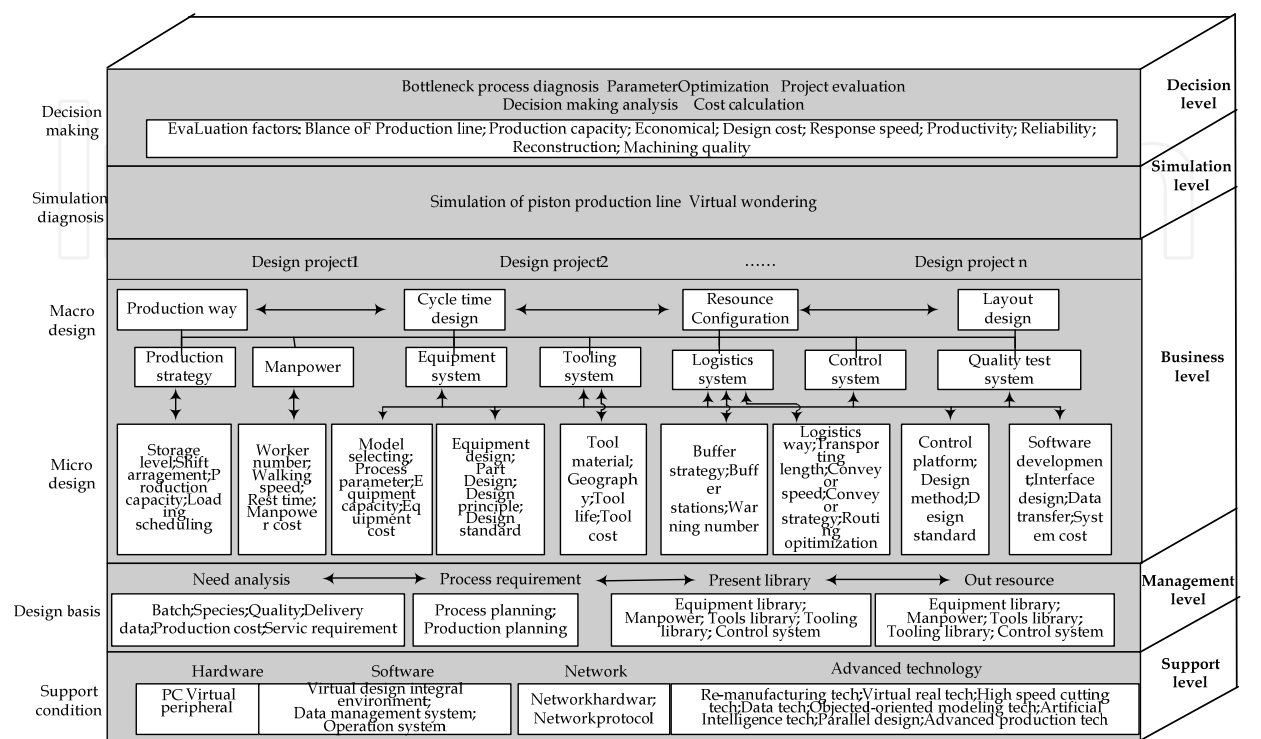

Fig. 3.1. Virtual simulation design frame of reconstructing piston production line

3.2 Object-oriented VD-PPL modeling and simulation analysis

Object-oriented technology is a design method focusing on the concept organization model of real-world mode, which is used with the entity to describe. With object-oriented method, it creates a basic resource library in the complex manufacturing environment of production line, and carries out the analysis and modeling for this library, which cannot only establish a unified framework to describe, design and complete system, but also can better reflect the hierarchy relation between various entities, and establish simulation model to reflect the real production environment. Based on manufacturing environment of production lines, for the piston production line modeling, it is used object-oriented modeling techniques.

3.2.1 Object modelling of Piston Production Line

Modeling for the piston production line not only needs to build three-dimensional geometry of physical entities in a virtual environment, but also needs to define the hierarchy relationships and interactions containing a variety of resource objects. For example, when designing manufacturing processes, it is necessary to define the relationship about of the process and the objects such as machine tools, process parameters, tools and other objects. However this relationship is static without dynamic behavior. Among the above objects, for the machine tools, it has the loading, manufacturing processes, unloading the workplace and other object behaviors (Methods of operation), and interact with other objects by the

message passing mechanism. For example, when the simulation of production lines is running, machine tools, buffers area, cutting tools, measuring tools and other objects will interact with each other and the dynamic behaviors will appear.

As it is known, object modeling of piston production line contains three parts: the description of object relations, object behavior and object interaction, which join together to achieve mapping modeling from reality to virtual simulation environment of the piston production line. Therefore, the VD-PPL modeling process is defined as follows:

1. Establish the physical model of VD-PPL

In the simulation environment, make the object model reflect the physical entity of the real piston production line.

2. Establish the logical model of VD-PPL

The logical model contains static logic model and dynamic logic models. Among these, the static logic description the modeling for internal properties of the piston production line, structure and behavior and so on, which reflect the static properties of all objects and relationships of the piston production line.

The dynamic logical is used to describe the dynamics behaviors and dynamic interactions on the piston production line, and to achieve the description of its dynamic characteristics by adding the simulation clock, event controller and other simulation-driving mechanisms, which can reproduce the running condition of description of piston production line to get the simulation results of piston production line.

3.2.2 VD-PPL analysis method

In QUEST, it is applied the model description with the object-oriented techniques, which can make the model reusable and modifiable. But its object model is mainly used for the simulation, and the description of the static object model is not more comprehensive than other object-oriented methods which can be difficult to fully describe the hierarchy and static characteristics of restructuring piston production lines.

UML is one of the modeling language based on Booch, OOSE methods and a variety of OMT methods, which is the product of the unified and standardization of modeling approach. It is proper for all stages of system development, and can establish the static structure and dynamic behavior model of the system. UML is a graphical modeling language, which includes five categories:

1. Case figure

Describe the functions of the system from the viewpoint of the user, and point out the operator of all the functions.

2. Static figure

Include the class diagrams, object diagrams and package diagrams. The class diagram is used to describe the static structure of class in the system, object diagram is a case of class diagram, and package diagram is used to describe the system hierarchy.

3.   Behavior diagram

Describe the dynamic model and the interactions of composition objects in the system, including state diagrams and activity diagrams. State diagram is used to describe all possible states of the objects and transfer conditions of the incident state, usually the state diagram is supplement of the class diagram; activity diagram is used to describe the activities and the constraint relationship between activities meeting the requirements of cases, which can be easily expressed in parallel activities.

4.   Interactive diagram

Both sequence diagrams and collaboration diagrams are used to describe the interactions between objects. Sequence diagram is used to show the dynamic cooperative relationship between objects, and collaboration diagram emphasizes collaborative relationships between objects.

5.   Implementation diagram

It is used to describe the features of the system, including component diagrams and configuration diagram.

Although the use of UML modeling method can well describe the object relations of VD-PPL, the modeling process is complex and model implementation is more time-consuming and difficult when UML is used to describe the complicated and discrete object behaviors and interactive relationship, because of the characteristics of random, discrete and others. QUEST simulation platform based on virtual manufacturing technology, not only supports the physical modeling of resource objects with better virtual visual interface, but also fully supports the simulation of object-oriented discrete/continuous events, which can be the important tools of the simulation and analysis of the production process. Combining the advantages of QUEST and UML, the paper proposed VD-PPL simulation modeling method, as shown in Fig.3.2.
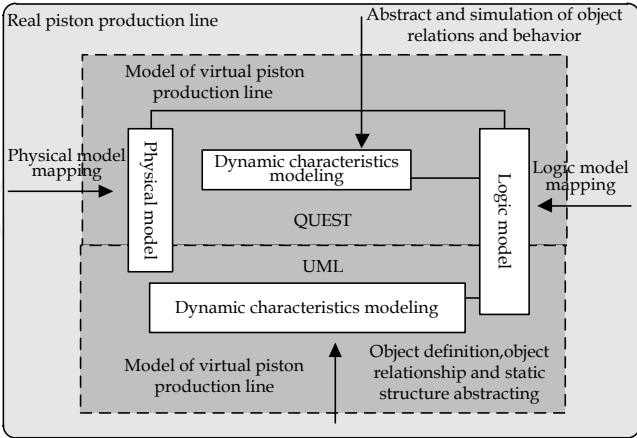

Fig. 3.2. VD-PPL simulation and modeling method based on QUEST+UML

In Fig.3.2, VD-PPL simulation modeling can be divided into two parts: the virtual physical modeling and virtual logical modeling. Virtual physical model is visual appearance of the logical model in a virtual environment, and it focuses on describing the three-dimensional geometry corresponding to the physical entity of the real production line. Therefore, virtual

physical model is the foundation of layout design of piston production line and visual simulation. The virtual physical model is divided into virtual static characteristics modeling and dynamic characteristics modeling. Virtual static characteristics modeling includes customization of all the objects on the production line and the description of the relationship between objects, and virtual dynamic model describes the dynamic behavior of the object itself and of interactions between objects. VD-PPL simulation modeling focuses on establishing the virtual logical model of the production line piston.

In VD-PPL modeling process, the contents are established by QUEST as follows: 1) the virtual physical model mapping corresponding to physical entities of the piston production lines; 2). the virtual logical model of VD-RPPL object relationship and object behaviors. Piston production lines describe object definition of the resources, object association and the static structure abstracting and other processes with UML.

3.3 Static properties modeling of Piston Production Line object

For UML modeling methods, the class object is an abstract for some public, private or protective properties and the corresponding behaviors. According to the common features of restructuring piston production line, all the piston production lines can be defined abstractly as a production line class. The production line class can be consider as the base class of VD-PPL modeling, the properties of production line class include the identification of production line, names of production line, maximum machining diameter of piston, minimum machining diameter of piston, and behaviors of the production line class includes getting the costs of production line, accessing the actual production cycle and availability calculation and so on. Fig.3.3 is UML class diagram between the base class of piston production lines and production lines class.

Production line class
-ID: int   +Name of production line: char   +Model of production line: char   -Maximum machining diameter of piston: double   -Minimum machining diameter of piston: double   -Maximum height of piston: double   +Actual cycle: double   -Production planning: double   -Cost: double   -Reconstructing time: double   +Layout ID: int   -Availability rate of production line: double   -Manufacturing products: int
+Getting the costs of production line: double   + Getting the actual production cycle: double   +Getting constructing time: double   +Availability calculation: double   +Getting the quantity of manufacturing products: int   +Utilization calculation: double

Fig. 3.3. UML classes diagram of piston production lines class

3.3.1 VD-PPL static hierarchical relationship

According to the hierarchical relationships of a piston production line, that physical equipment, process technology, logic control and simulation supporting classes are derived from the production line class. The physical equipment class is corresponding to production entities in the reality, such as processing equipments, logistics equipments and so on. No entity is correspond with the process technology class in the real production line, such as Cycle Process, Load Process, Unload Process, production planning and tasks and other process contents. The logic control class is used to describe the logical relationships between objects, such as AGV control logic, labor control logic, conveyor control logic. The simulation supporting class is applied for describing the interaction process time of production line simulation, events, and data performance statistics and other simulation supporting objects. According to the relationship between base classes and derived classes, the static hierarchy of various objects in VD-PPL design process, as shown in Fig.3.4.
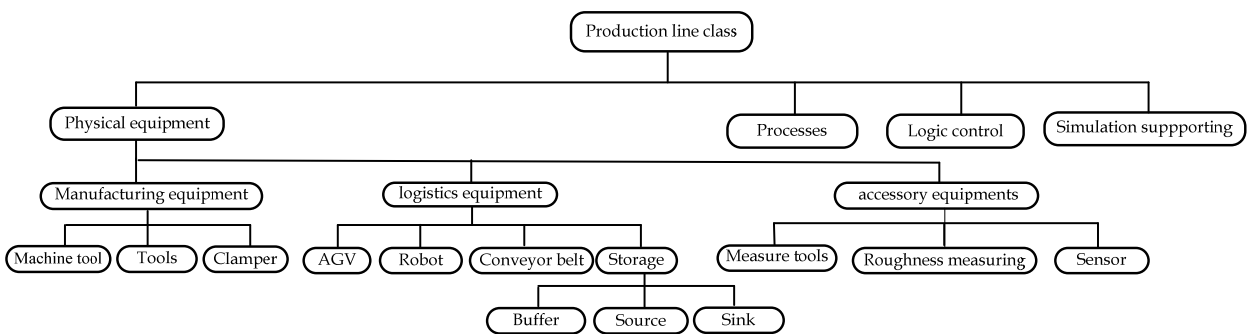

Fig. 3.4. Static hierarchy of piston production line objects

3.3.2 Physics equipment

Attributes of the physics equipment class is divided into physics, processes, function and status attributes. Physical attributes define the static property of resources, such as identity, name, geometry, size, color, accuracy, etc.; Process attributes define the actions completed by relative motion or action of two or more resources, such as utilization, cycle time and so on; Functional attributes define series of a higher level of functional units processes formed by the combination series of processes, on behalf of the ability of resources; State attributes is used to define whether the resource is in using, waiting, idle state or the state of repair, to guide the dynamic dispatch of production resources. The manufacturing equipment class, logistics equipment class, accessory equipment classes are derived from physical equipment class according to their hierarchy.

1.   Manufacturing equipment class

Processes equipment mainly refers to the equipment that can complete one or more process technology. The physical attributes of manufacturing equipment include equipment identification, equipment specifications, failure rate, repair rate, etc., and its process attribute also includes equipment utilization, etc.; it is shown in Fig.3. 5(a).

2.   Logistics equipment class

Logistics equipment class is responsible for transportation and the storage of the work piece and materials between logistics equipment, such as AGV, conveyor, robot, storage devices

(Source, Sink, Buffer, etc.). Workers (Labor) who complete the transportation and storage of materials can also be treated as abstract logistics equipment. Logistics equipment class is used to describe the properties and methods of equipment and workers that implement the transportation function of the work piece and materials, and it is also used to describe the reconfiguring time, cost, utilization, work piece delivery time of logistics equipment in the process of reorganization objects. According to the definition mode of processing equipment class, the attributes of the logistics equipment class can also be divided into physical, process, functional and state attributes. Especially, the physical attribute includes equipment number, name, size, cost, geometry, size, color and so on. The process attribute includes utilization, delivery times, reconstructing time, delivery speed, acceleration/deceleration, etc. the functional attribute includes the maximum specifications and length of work pieces or materials, the maximum transportation quantities of the work pieces, the maximum work piece capacity and so on. UML class diagram of the logistics equipment is shown in Fig.3.5 (b). AGV, convey, robot and storage classes are derived from logistics equipment class

3. Auxiliary equipment class

Auxiliary equipment is mainly service as the measure and other works to make sure the processes are completed smoothly and accuracy. The auxiliary equipment class is the abstract of such equipment, and its attributes includes device identification, name, size, cost, measure items, measure accuracy, measure time, reconfiguring time and so on; Its behavioral approach is: to get the cost of auxiliary equipment, the reconfiguring time of auxiliary equipment and the measuring time of auxiliary equipment so on. UML class diagram of measure equipment class is shown in Fig.3.5 (c). According to the different measure items, measuring device, roughness measurement, sensor type, and other classes are derived from the auxiliary equipment class.

manufacturing equipment class	Logistics equipments class	auxiliary equipments class
+Name: char -No. :long -Quantity: int -Description: char -Productivity:double -ID:int +Name of production line: char +Model of production line: char -Maximum machining diameter of piston: double -Minimum machining diameter of piston: double -Maximum height of piston: double -Minimum height of piston: double -Production planning: double +Actual cycle: double -Cost: double -Reconstructing time: double +Layout ID:int -Availability rate of production line: double -Manufacturing products:int	+Name: char -No. :long -Quantity: int -Description: char -Cost: double -Reconstructing time: double -ID:int +Max. transportation capacity of parts:int +Transportation speed: double +Acceleration: double +Name of production line: char +Model of production line: char -Maximum machining diameter of piston: double -Minimum machining diameter of piston: double -Maximum height of piston: double -Minimum height of piston: double -Production planning: double +Actual cycle: double -Cost: double -Reconstructing time: double +Layout ID:int -Availability rate of production line: double -Manufacturing products:int	+Name of measuring tools: char -No. of measuring tools :int -Specification - Measure accuracy +Measuring ability:char -Quantity: int -Single detecting time:double -ID:int +Name of production line: char +Model of production line: char -Maximum machining diameter of piston: double -Minimum machining diameter of piston: double -Maximum height of piston: double -Minimum height of piston: double -Production planning: double +Actual cycle: double -Cost: double -Reconstructing time: double +Layout ID:int -Availability rate of production line: double -Manufacturing products:int
+Getting the costs of production line: double + Getting the actual production cycle: double +Getting constructing time: double +Availability calculation: double +Getting the quantity of manufacturing products:int +Utilization calculation: double	+Getting the costs of production line: double + Getting the actual production cycle: double +Getting constructing time: double +Availability calculation: double +Getting the quantity of manufacturing products:int +Utilization calculation: double	+Getting the costs of production line: double + Getting the actual production cycle: double +Getting constructing time: double +Availability calculation: double +Getting the quantity of manufacturing products:int +Utilization calculation: double
a) manufacturing equipment class	b) Logistics equipments class	c) Detecting auxiliary equipments class

Fig. 3.5. Auxiliary equipment classes

3.3.3 Processes class

In order to describe the processes during the piston manufacturing, the process class is acted as base class of VD-PPL process modeling, and those attributes include ID, names, process technology contents; its behavioral approaches are: working hours calculating, efficiency calculating and process, production planning, production scheduling classes and so on can be derived from the process class.

Attributes of the process class contain process ID, name, content, process priority, the number of work piece, number of workers, number of AGV and equipment, average cycle time and distribution of cycle processing time. Those behavioral approaches include defining the work piece priority, logical sequence of process, equipment selecting, working hours calculating, auxiliary process arranging, and so on. According to the classification of process technology, the process class is divided into the initial running process, loading process, recycling processing technology, unloading process, maintenance process classes etc. UML model of process technology class is shown in Fig.3.6 (a).

Attributes of the production scheduling class include ID, name, description of production arrangements, the number of shifts, shifting time, stopping time. Those behavioral approaches contain shift schedule, the calculation of expected stopping time of single work piece, needed equipment between arrange the associated shifts and so on. UML model of the production scheduling class is shown in Fig.3.6 (b).

Attributes of production planning class contain ID, name, and content, description of production plan, production, delivery date, and cost. Those behavioral methods include production cycle calculating UML model of production planning class is shown in Fig.3.6 (c).

Attributes of the process parameters class include ID, names, spindle speed, horizontal-feeding speed, vertical-feeding rate, cutting depth. Its behavioral methods contain machine tools selecting, tools selecting and measuring tools selecting, and so on, they are shown in Fig. 3.6 (d).
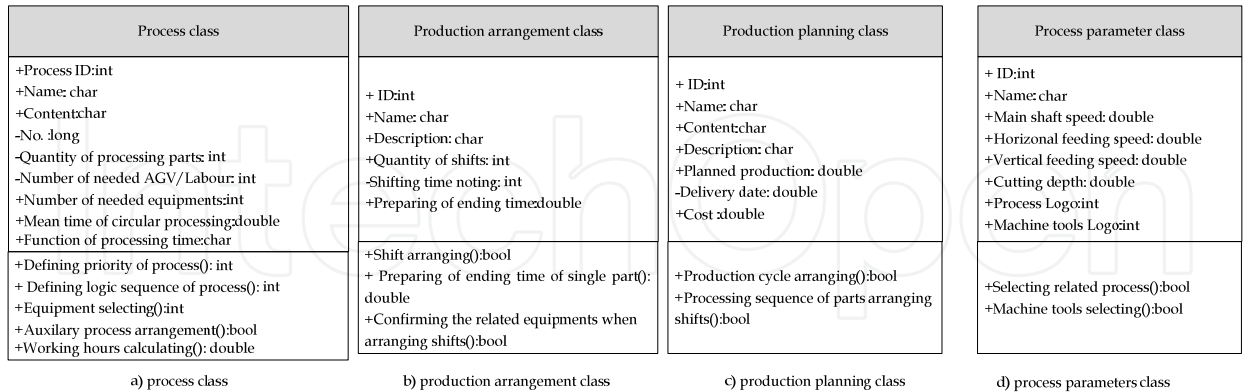
Process class	Production arrangement class	Production planning class	Process parameter class
+Process ID:int +Name: char +Content:char -No. :long -Quantity of processing parts: int -Number of needed AGV/Labour: int +Number of needed equipments:int +Mean time of circular processing:double +Function of processing time:char	+ ID:int +Name: char +Description: char +Quantity of shifts: int -Shifting time noting: int +Preparing of ending time:double	+ ID:int +Name: char +Content:char +Description: char +Planned production: double -Delivery date: double +Cost :double	+ ID:int +Name: char +Main shaft speed: double +Horizonal feeding speed: double +Vertical feeding speed: double +Cutting depth: double +Process Logo:int +Machine tools Logo:int
+Defining priority of process(): int + Defining logic sequence of process(): int +Equipment selecting():int +Auxilary process arrangement():bool +Working hours calculating(): double	+Shift arranging():bool + Preparing of ending time of single part(): double +Confirming the related equipments when arranging shifts():bool	+Production cycle arranging():bool +Processing sequence of parts arranging shifts():bool	+Selecting related process():bool +Machine tools selecting():bool
a) process class	b) production arrangement class	c) production planning class	d) process parameters class

Fig. 3.6. UML class diagram of process technology derived class

3.3.4 Logic control class

Logic control is activity on the selection and scheduling functions of production resources, and logic control class is used to be an abstract description of interaction decision-making behavior between the different resource objects in a specific time. Attributes of the logic

control class contain the controller ID the number of control objects, logical calculation priority. Those behavioral methods include the definition of initialization logic, processing logic, part routing logic, resource selection logic and other selecting modes. The meanings of the logical models are shown in Table 3.1, and the logical hierarchy relationship of the control class is shown in Fig. 3.7.

Logic mode	Meaning
Initial Logic	Control production resource completes the decision-making process initialization.
Process Logic	Control production resource complete the decision-making of loading process class, recycling processing technology class, unloading process
Part Rout Logic	Control work piece complete the decision-making of routing way from one object to another.
Request Selection Logic	Control the decision-making of resource selecting behavior with process technology.
* Queue Logic	Deal with the sequence of work piece when routing from Buffer object to other production resources.

* Queue Logic is only used for Buffer.

Table 3.1 VD-PPL logic definition

Processing logic is used to define the sequence of processing objects, proportion relations of process objects handling. Routing logic is primarily used to define the model of bottom objects of the work piece. Queuing logic is mainly used to define queuing methods.
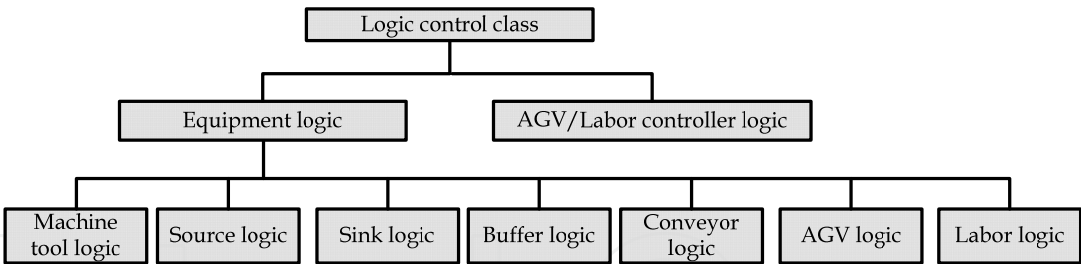
Fig. 3.7. Hierarchy diagram of logic control class

Equipment logic class	AGV/Labour controller class
+ Initial Logic:int +Processing/checking processing Logic: char +Process dealing of parts input logic:int + Rout Logic of Part output +Queuing logic	+ Initial model : Model of Initial Logic +Selecting model of AGV/Labour: Selecting model of AGV/Labour +Routing model of AGV/Labour: Routing model of AGV/Labour +Stopping model of AGV/Labour :Stopping model +Rout selecting model of AGV/Labour:
+Setting up the model of Initial Logic():Model of Initial Logic +Setting up the processing model of process():Processing/examination equipment logic +Setting up the process model of part input():Model of part input + Setting up the Rout Model of Part output():Rout model of part +Setting up queuing model: Queuing logic model	+Setting up the model of Initial Logic():Model of Initial Logic +Setting up the selecting model ():Selecting model of AGV/Labour +Setting up the routing model ():Routing model of AGV/Labour + Setting up the stopping model of Part output():Stopping model +Setting up rout selecting model: Rout selecting model
a) Equipment logic class	b) AGV/Labour controller class

Fig. 3.8. UML class diagram of equipment logic and AGV/Labor controller logic

The equipment logical device is mainly used in loading the work piece, processing the work piece and unloading the work piece, and the equipment need complete judgment and decision-making. Its UML class diagram is described in Fig.3.8 (a). AGV / Labor control logic means that AGV / Labor controller sends logic instructions to AGV / Labor when the production resources (such as equipment) is set on AGV / Labor , and its UML model is shown in Fig. 3.8 (b).

The piston product line also includes other logic, such as: Initial Logic, Request Input Logic, Part Input Logic, Request Selection Logic, etc.

3.3.5 System interaction class

System interaction class provides function and mechanism of the virtual simulation, and it used to the abstraction supported by dynamic simulation model, including time management, event table handling, creation and elimination of object, generation of random number, data collection and processing of statistics objects, etc., which does not correspond to physical entities in the real production line. Event class, time, etc. is derived from it.

Attributes of event class includes ID, names, events, object identity for demanded resources, corresponding process identifies, the type of events, and occurred time of the event.

Attributes of time class contain ID, names, events, active objects, passive objects, happening time, time to maintain the global simulation, record and order the events recorded according to the event points, determining the next earliest occurrence of future events and happening time and advance simulation clock and so on.

3.4 Dynamic properties modeling

The piston production line is a typical discrete event system. There have been many discrete event systems about dynamics modeling and analysis methods. It contains three types of modeling-logic level, algebra-level and performance level at least. An analysis method of the logic level includes finite automation /formal language method, Petri Net methods and so on. Petri Net methods began to be used for manufacturing system modeling from the early 1980s, which can analyze and describe the dynamic behavior of manufacturing systems well. But, with the system parameters increasing, Petri Net modeling and analysis become more and more difficult. Algebraic methods contain max/min algebra and finite recursion. Min/max algebra applies algebraic methods as a tool to establish the state equation of the time of the incident, according to the running relationship of the system, and then get the processing cycle, utilization and other parameters of the system by eigenvalue analysis. But with the parameters increasing, the state equation will bring out the dimension explosion, solvability variation, and analytical ability weakening. Performance levels contain: queuing network, perturbation analysis, and simulation modeling approach. Queuing theory is generally used for the qualitative analysis of system; perturbation analysis method will generate dynamic disturbance because parameters on the production line is much more, which is more difficult to describe the system dynamic process with tables and dynamic equations. The piston production lines often have uncertain activities, and also affected by constraints of internal/external objects of the system. And these objects are often affected by some other uncertain activities, leading that the variable state of the piston production line presents uncertainties, which will take the larger difficulties for analysis and modeling.

Apply object-oriented modeling method to establish the dynamic model piston production line to simulate and model effectively for dynamic characteristics of piston production line.

3.4.1 Object dynamic model based on UML+QUEST

Before establishing the virtual dynamics model of the piston production line, it is necessary to analyze the object of the piston as follows:

The behavior model of the state changes of all the objects is established based on the object behavior and messaging mechanism with the UML state diagram. Figure3.9 describes UML state diagram of the state changes in the process of the piston machining tool, in which, "⊂⊃"is the state of the machine in the process of machining the piston. "T" is the interactive relationship of states changes.
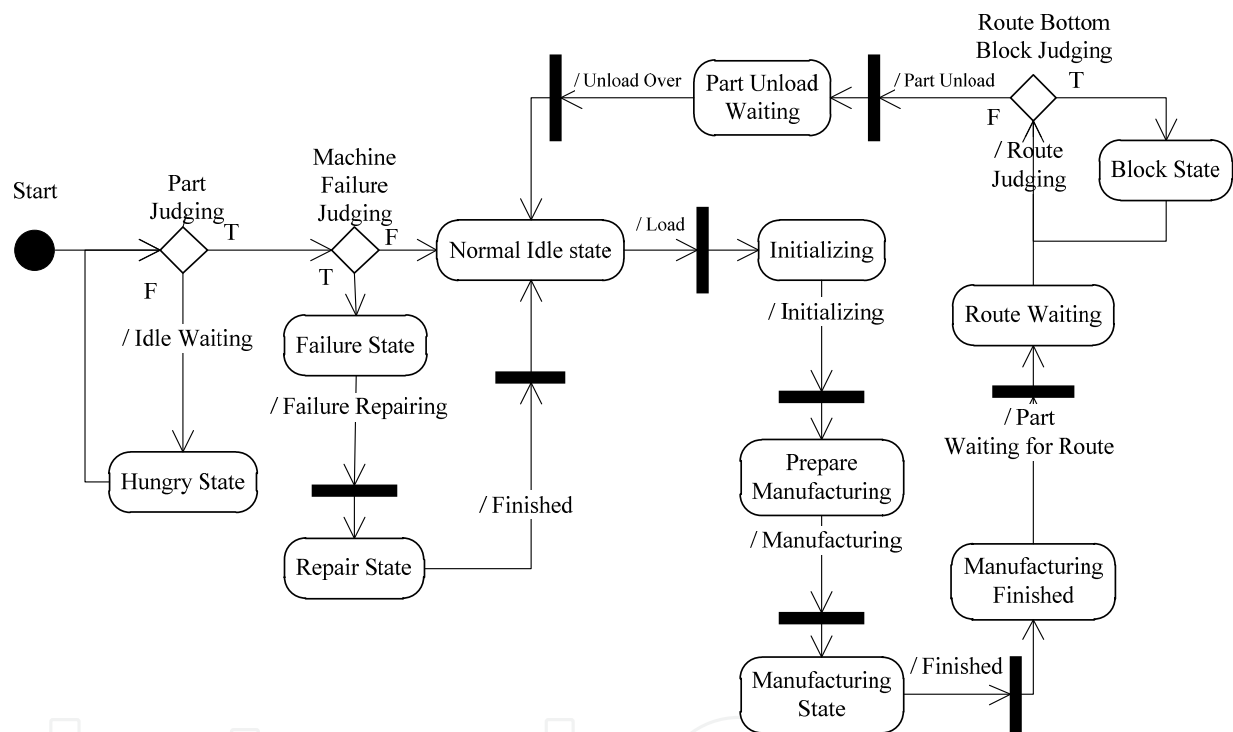
Fig. 3.9. UML state diagram of machine tool when piston is processed

The object relations, behavioral control, object interaction model are established with UML sequence and collaboration diagrams to fully describe the association relationship of various objects during piston processing. Figure.3.10 describes UML sequence interaction diagrams of labor controller, labor, buffer, and machine tool objects.

After analyzing the interaction behavior of dynamic models, in QUEST, virtual dynamic model of PPL is established, and the modeling steps are shown in Fig.3.11.

1. Establishing the physical model

The virtual physical model is the basic task of VD-PPL. The physical model is an abstract description of a real model of the piston production line in a virtual environment. According to the geometry, establish the virtual physical model of the resource objects with three-dimensional geometric modeling functions (or other 3D solid modeling software,
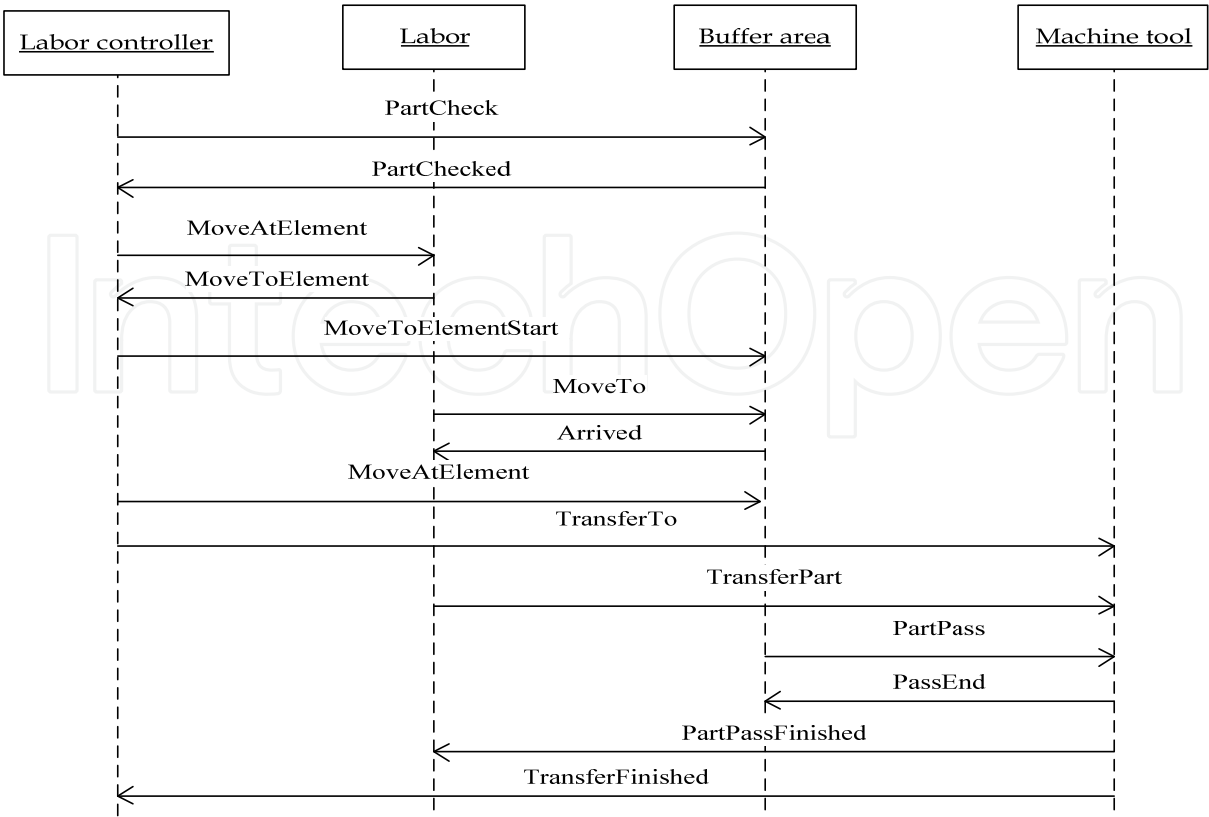
Fig. 3.10. UML sequence interaction diagram of all the objects in the piston conveying
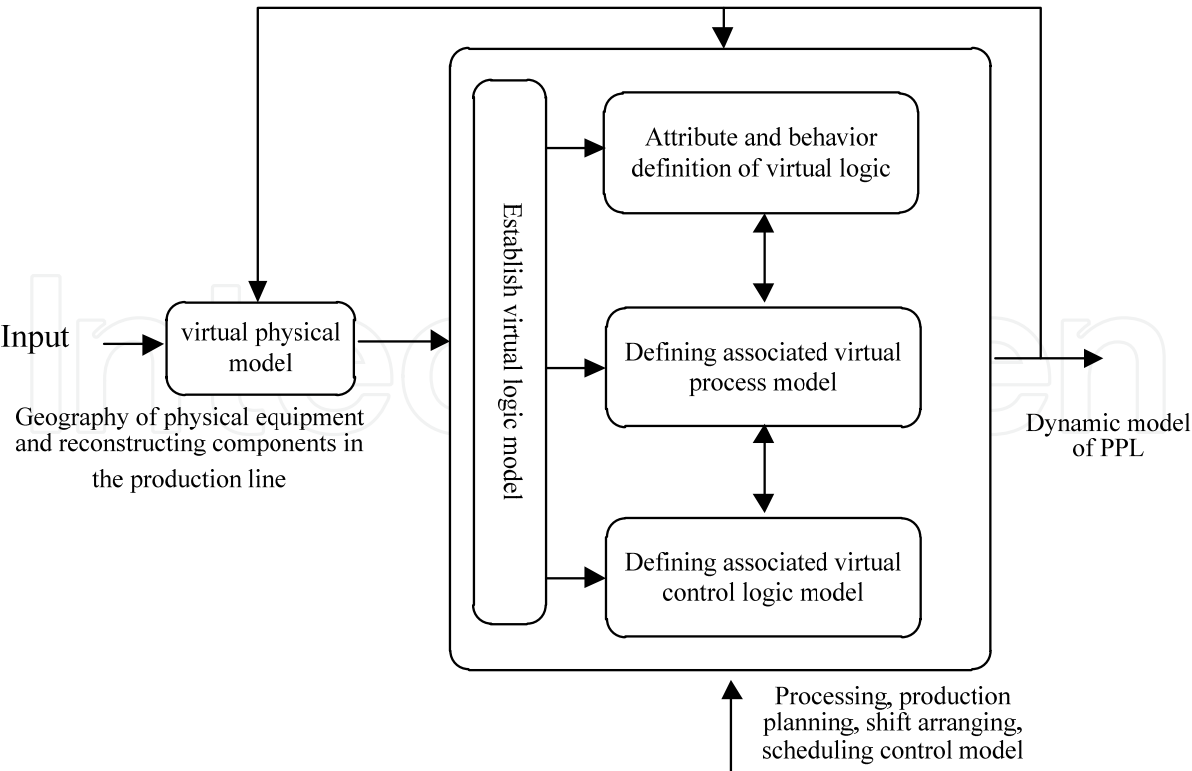
Fig. 3.11. Steps of building virtual dynamic model

transferring to the QUEST integrated environment through the graphical interface). Virtual physical model is established as follows:

1. Make sure all modules of the equipment of the piston production line.
2. According to geometry, shape and size of the equipment, establish the virtual physical model library, which can make the physical model with the function of the reconfiguration and reuse in QUEST environment.
3. According to the physical entity of the resource object, layout the piston production line will be carried out.

2. Establishing virtual logic model of VD-PPL

Abstracting from the virtual physical model to virtual logical model, it needs to complete the following tasks:

1. Complete the abstract definition and description for the attributes and behaviors of virtual physical model. On the one hand, these attributes are used to simulate, on the other hand, are applied with equipment management and reconfiguration of objects.
2. Define the virtual process model associated with the virtual physical model to make the established resource objects with relationship, make the object model with dynamic behaviors, and achieve the function of virtual machining simulation during the production process of piston machining.
3. Define the virtual control logic model associated with the virtual physical model. So that the established model can describe the logic relationship of all the behaviors of objects and make the dynamic behavior of the model occur orderly and circularly.

After finished these steps above, the production line physical model can be changed into the virtual logic model. The virtual model with the process and the logic can be used as visual simulation and dynamically analyze the piston manufacturing process supported by the system simulation strategy and simulation clock.

3.4.2 System simulation strategies of VD-PPL

For the piston production line, there are a variety of objects which are interacted and affected with each other. If the piston production line is virtually simulated, the behaviors of individual object need to be united in the same the simulation clock (simulation time) range, and determine simulation strategies and pushing methods of simulation clock to complete the analysis of the dynamic model. VD-PPL simulation strategies are established based on the advantages of an integrated event scheduling method, activity description method, process interaction method and other simulation strategies. Simulation strategy flow is shown in Fig.3.12.

Changing of the VD-PPL simulation clock time is depended on the simulation step, and simulation time step has the following attributes:

1. It can be a fixed step (The step of controlling simulation speed is fixed), or variable step (Promote the event behaviors, and the simulation clock is pushed forward to the happening point of event directly, the simulation step is variable).
2. Because the changing of the object 's state is random, the step of simulation clock is random too.
3. Between two adjacent events, the simulation clock can overcome these "inactive" period. It can be pushed from the first to the next happening time of event activities occurs.
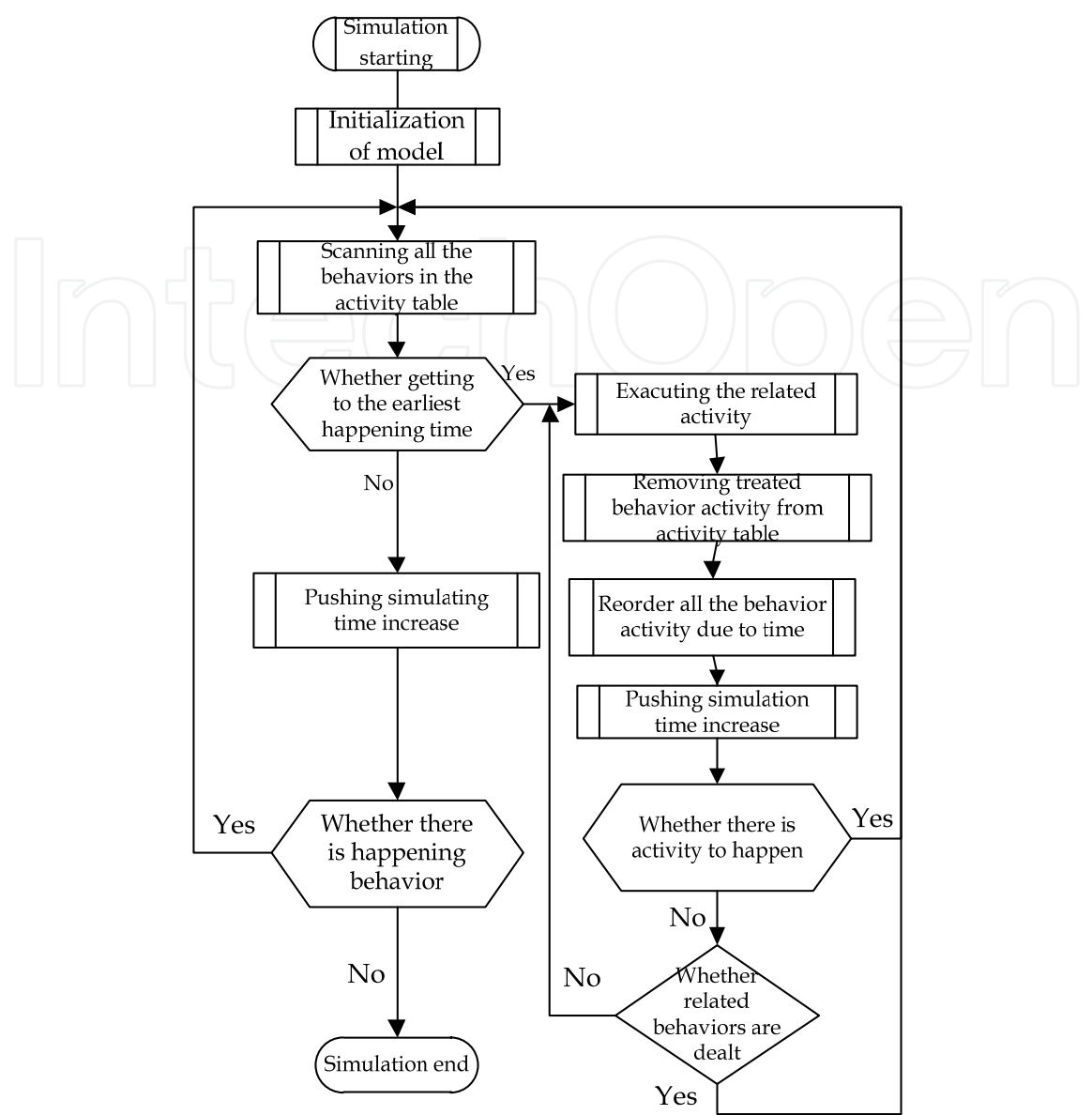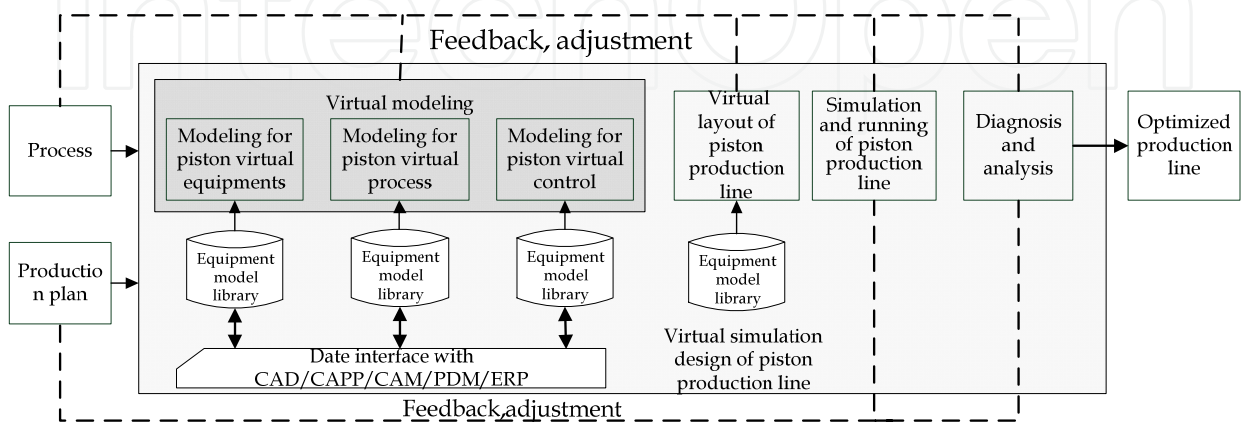
Fig. 3.12. VD-PPL simulation strategies flow

Fig. 3.13. Virtual design procedure of the piston production line

3.5 Virtual design procedure of piston production line

Virtual design procedure of the piston production line is shown in Fig.3.13. Process planning and production planning are the basis for the design process. Under the virtual model of the production line, the virtual layout planning is easy to be built, and if set the simulation clock in the virtual environment, it could get some simulation results which can be used to diagnose the bottlenecks and optimize the related parameters of the production line.

4. An instance of simulation and analysis of piston production line

By analyzing the status of an existing production line and design requirements, complete the virtual modeling, layout, simulation analysis and diagnosis of this line, and thus re-design the line to make the full range of logistics flow unblocked.

4.1 Status of production line and design goals

The line is affiliated to artificial lines, process routing is : finish turning of the spigot→ rough boring of pin hole → finish turning of cylindrical, rough finish and finish turning of the groove of iron hoop→ finish turning the groove of aluminum hoop→semi-finish boring of pin hole → turning of retaining ring groove and outside pin shaft→rough turning of combustion chamber→ fine turning of combustion chamber →fine turning of outside round→ fine turning

Process contents	Equipment code	Number	labor	Shifts	Working Procedure Time (s)
Finish turning the spigot	M1	1	L1,1	1	31
rough boring pin hole	M2	1			43.28 (Double work stations)
Finish turning cylindrical, and rough finishing turning of the groove of iron hoop	M3	1	L2,1	2	74.3
	M4	1			74.3
Finish turning the groove of aluminum hoop	M5	1	L3,1	1	23.24
Semi-finish boring pin hole	M6	1	L4,1	1	76.4 (Double work stations)
Turning retaining ring groove	M7	1	L5,1	1	36
Turning outside pin shaft	M8	1			36
Rough turning combustion chamber	M9	1	L6,1	1	31.3
Fine turning combustion chamber	M10	1			50.26
Fine turning outside round	M11	1	L7,1	1	136.2
	M12	1			136.2
Fine turning roof surface	M13	1	L8,1	1	32
Fine boring pin hole	M14	1	L9,1	2	70.77 (Double work stations)
Rolling pin hole	M15	1	L10,1	1	14.7
Boring decompression chamber of pin hole	M16	1	L11,1	1	73.33 (Double work stations)

Table 4.1. Scheduling of processes on the piston production line

of roof surface→ fine boring of pin hole →rolling of pin hole →boring decompression chamber of pin hole. The parameters of all the processes are shown in Table 4.1.

Because piston species in one production line would be changed 3 to 5 times monthly, for the traditional piston production line, its design method cannot be respond rapidly, and the design of the process time is not balanced and so on, resulting in the serious workpiece products in the line and a serious unbalance labors and machines utilization. Aimed at these problems, ensure the re-design goals: the diameter of piston diameter is between 100 ~ 130mm, monthly production capacity of production line should be not less than 22,000 pieces/ month (two shifts), and cycle should be not more than 47s, the operator should be no more than 9, machine tools should be no more than 16.

4.2 Virtual modelling

According to the real production line, establish the physical models, some typically machines are shown in Fig.4.2 (a-d).
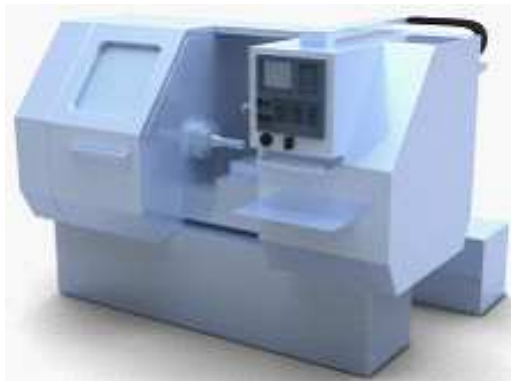
a) Virtual boring machine model BH30   b) Virtual boring machine model BH20
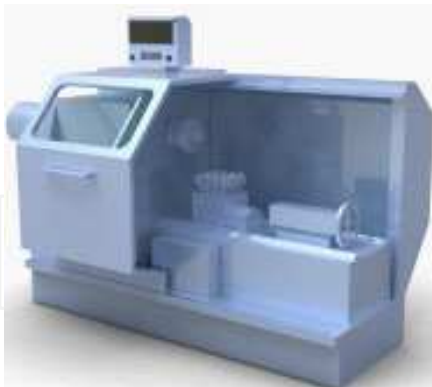
c) Virtual lathe model CAK6250   d) Virtual lathe model CK6146

Fig. 4.1. Physical models of piston line

4.3 Virtual design of piston production line

4.3.1 Virtual design parameters

The layout before optimizing is shown in Fig.4.2, its covers area S= 36772.3 ×5668.1mm² = 208.43m². The layout of the piston machine is very messy and there are many idle stations in

the middle part (These stations are reserved for some special processing procedures, but these machines have been moved to special equipment areas at present.). As the machine pitch is too far, and the machine position is not optimized, resulting in a waste of area in the line, and increasing walking distance and labor intensity.

4.3.2 Process parameters

After the establishment of the virtual physical models, the procedure of definition of the virtual process and control logic is shown in Fig. 4.3−4.7. To realize changes from the virtual physical model to the virtual logical model, because the line does not belong to automated production lines with the central control system, it does not need to create the central control system logic, but it is necessary to define the workers control logic (Labor Control, as shown in Fig.4.8) to control the following actions of the labors:

1. Routes and walking speed of workers, as shown in Fig. 4.9;
2. Rest time and its distribution of workers, as shown in Fig. 4.10-4.11;
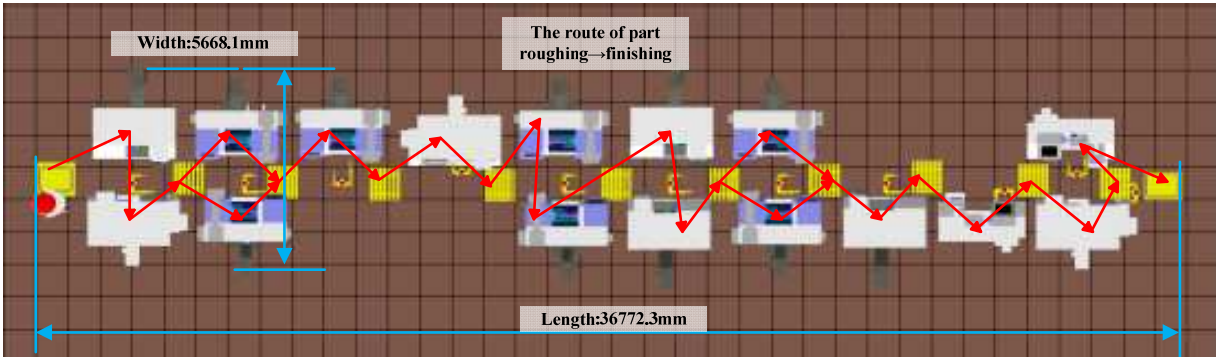
Fig. 4.2. Virtual layout and the connection way of process logic of equipment
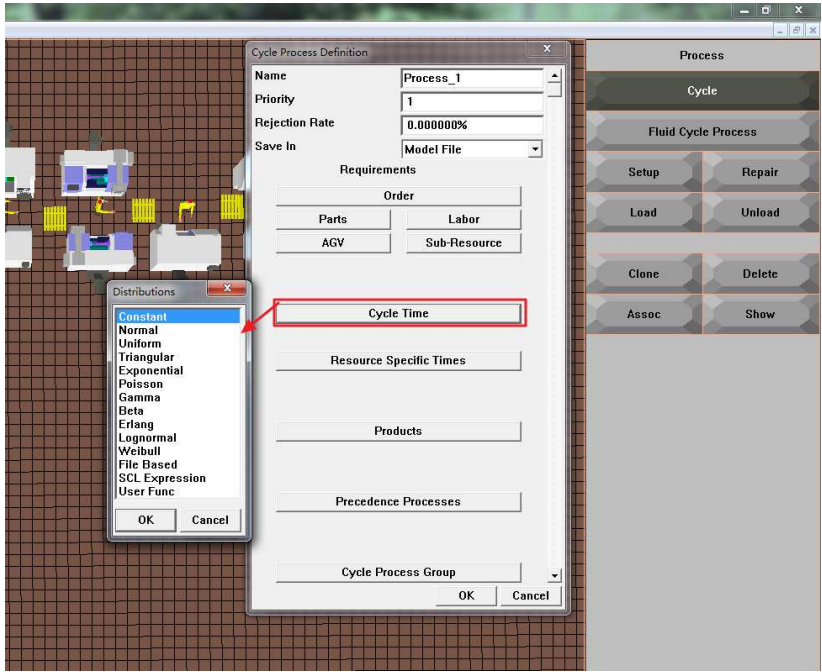
Fig. 4.3. Cycle process logic
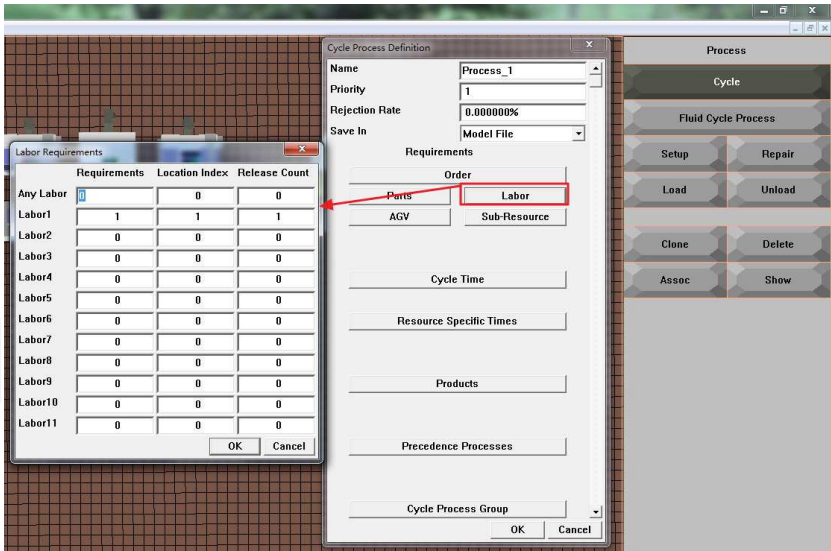
Fig. 4.4. Labor requirements of cycle process
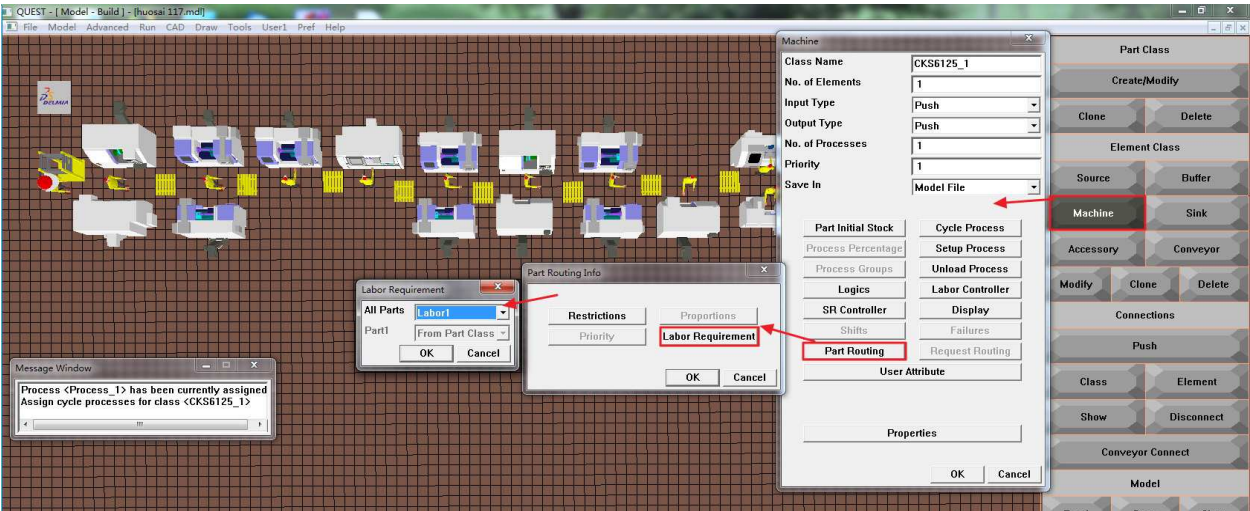
Fig. 4.5. Machine control logic associated with labor
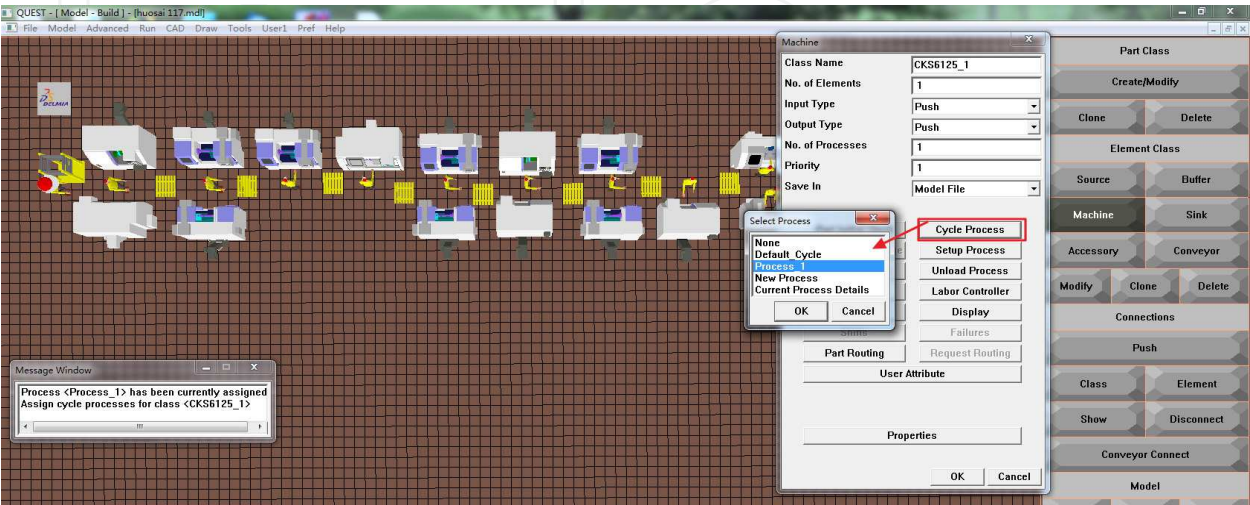
Fig. 4.6. Machine control logic associated with cycle process
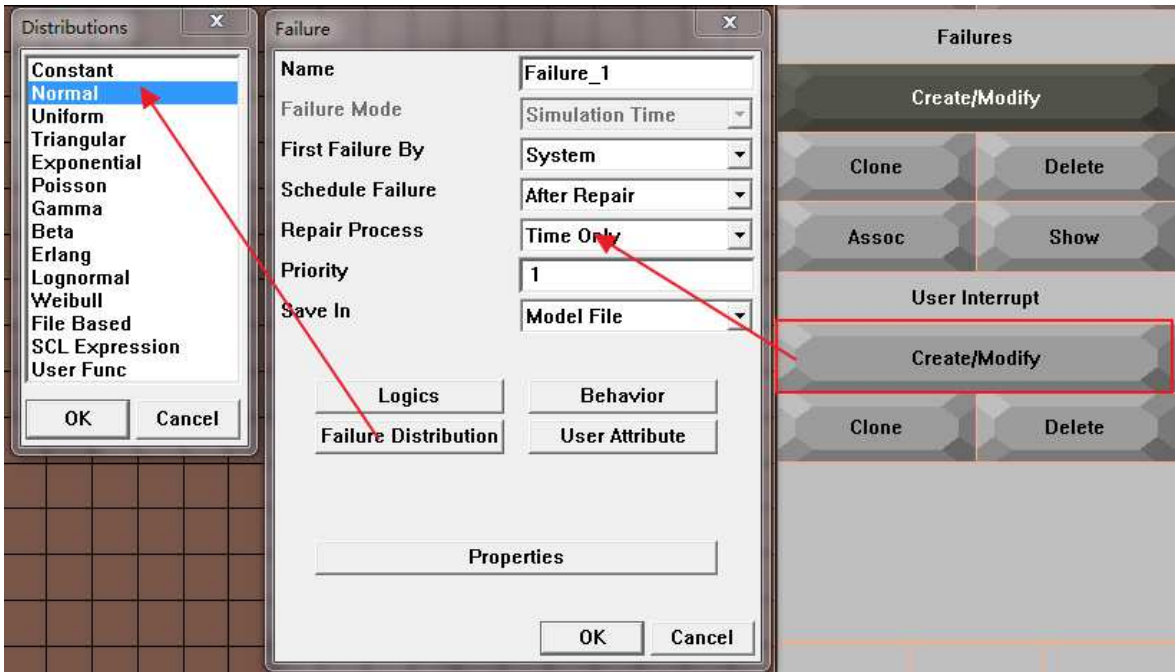
Fig. 4.7. Machine's failures setup

Fig. 4.8. Labor controller logic
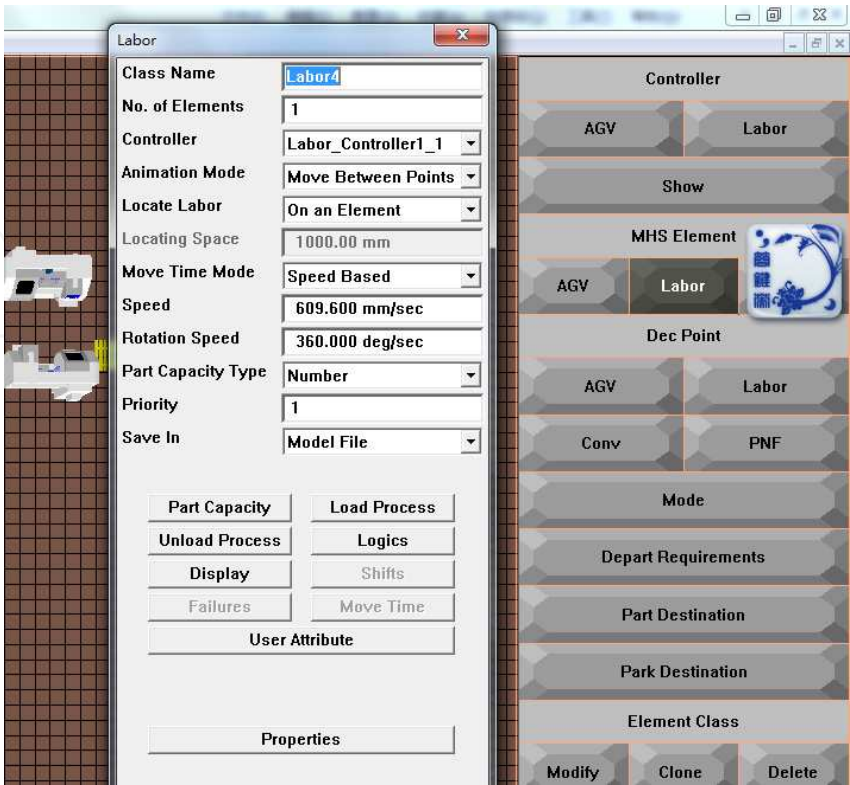
Fig. 4.9. Labor control logic
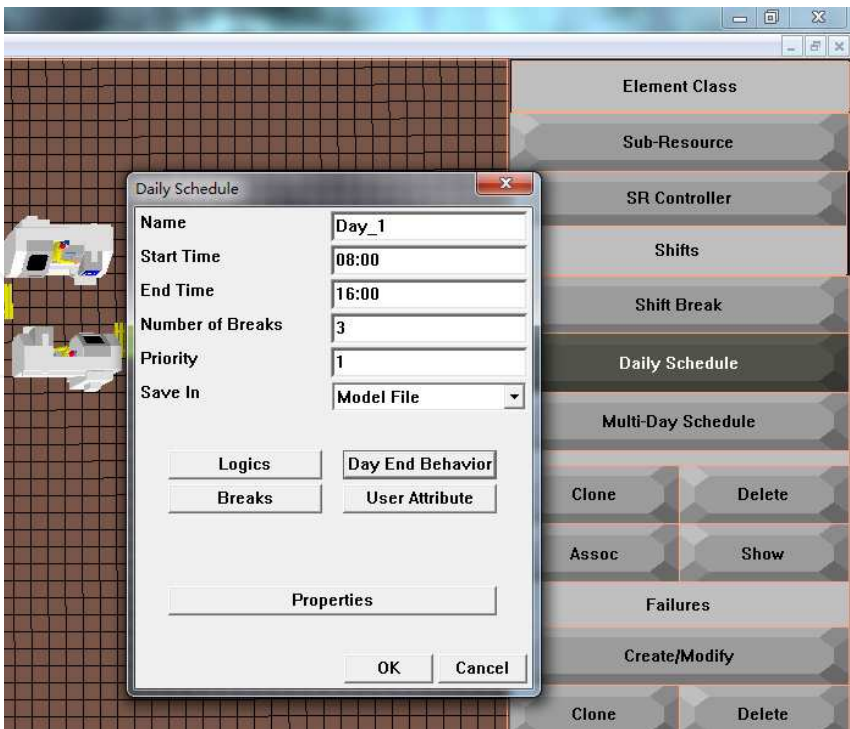
Fig. 4.10. Daily schedule
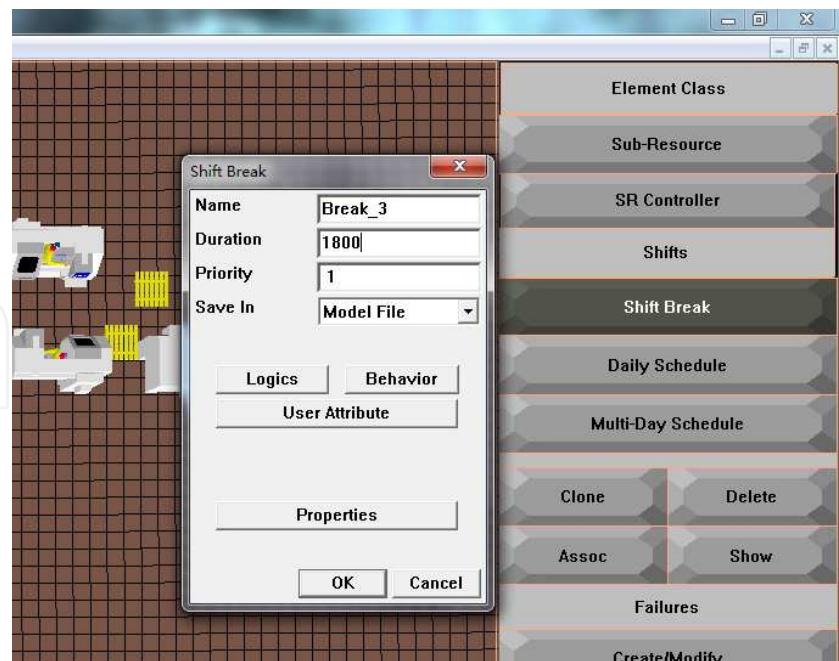
Fig. 4.11. Shift break

4.3.3 Simulation results

The statistical data after simulation includes output of production line, the work piece of buffer area, processing quantities of equipment, machine utilization, utilization of workers' working hours and walking paths and so on.

1. Work piece in the buffers

The number of the work piece in buffers under different simulation time is shown in Table 4.2. It is known that: The work pieces of B1, B3, B5 and B6 are more serious, with which it is shown that the processes after B1, B3, B5 and B6 are the bottleneck processes. However, only adjusting some parameters to improve some of the bottleneck process may trigger new bottleneck processes, so it is necessary to fully investigate and analyze with output of each machine per shift, machine utilization and labor utilization to provide adjustment strategies for balancing of the piston production line.

Buffer	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
1 hour	14	0	9	0	0	13	1	1	0	1
1 shift	90	0	58	1	97	85	0	0	0	0
1 week	440	0	270	0	469	436	1	1	0	0

Table 4.2. Accumulation number of parts in buffer

2. Production and cycle time

According to the relationship between the production and time, the cycle time of the entire production line can be calculated. Fig.4.12 shows that the production cycle tends to be stable gradually with simulation time increasing, and it stabilizes at 70.47s. With this value compared with each process time, it is easy to diagnose the bottleneck process of the line.

Figure 4.13 shows the relationship between process time of each machine and the real cycle time, it is shown that: there was a sudden change of output between the processes operated by worker L1 and L2. The same change occurs between the L3 and L4, L5 and L6, L7 and L6, meanwhile, it is also shown that cycle time is different with processes, the process operated by L1 is the smallest, up to about 35s, which means that the process has a greater redundancy. Suddenly changing point of process time happens in fine /rough turning of combustion chamber operated by L6 and finishing turning of cylindrical operated by L7, those processes are mostly near the entire cycle time. It is referred that those processes may be the most serious bottleneck process in the system.
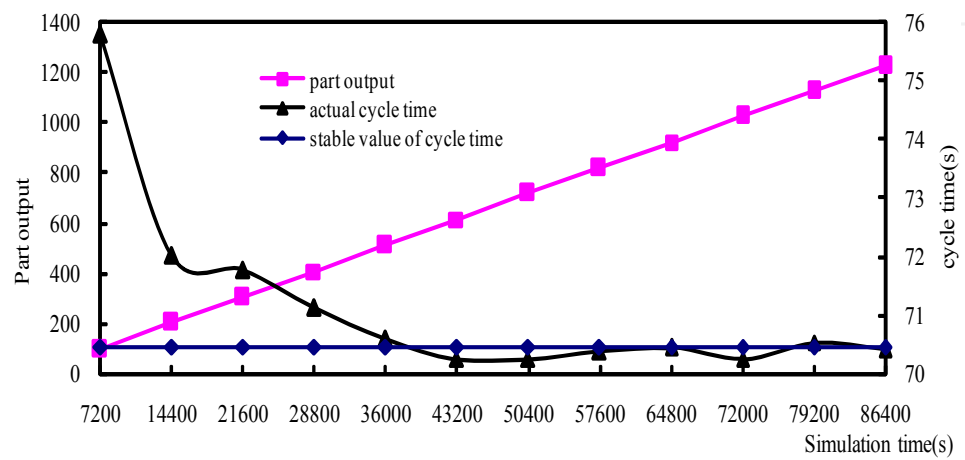
Fig. 4.12. Relationship between simulation time and cycle time
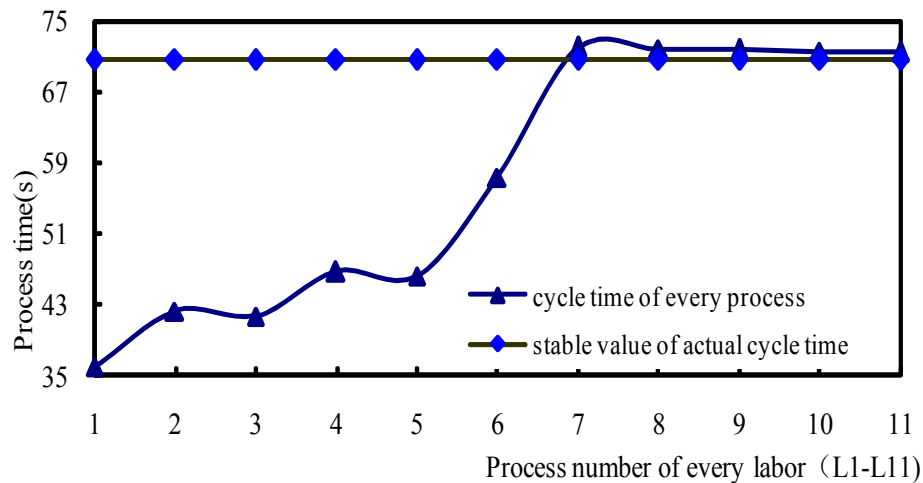
Fig. 4.13. Relationship between process time and actual cycle time of each unit

3.   Equipment utilization

Equipment utilization reflects the load of each machine. Under different simulation times, machine utilization is shown in Fig. 4.14. It is known that: when the line is in a steady state, the machine utilization does not change over time on the whole. But the difference of the utilization on each machine tool is much larger, namely: balance of this production line is very poor. The utilizations of M1, M3, M4, M6, M7, M8, M10, M11 and M12 are much higher, and utilization of finishing turning of cylindrical processes machined by M11 and

M12 is the highest, up to 94.6%. Considering the output of the all product line, cycle time, and machine utilization, it can be diagnosed that: the finishing turning of the outside round is the most serious bottleneck process. When adjusting and redesigning the production line, the adjustment should be begun from this process. Constrained by the bottleneck process, utilizations of M13 ~ M16 are relatively low. If adjusting those bottleneck processes, the utilizations of M13 ~ M16 can be significantly improved to carry out the purpose of logistics balance and increasing output of the whole production line.
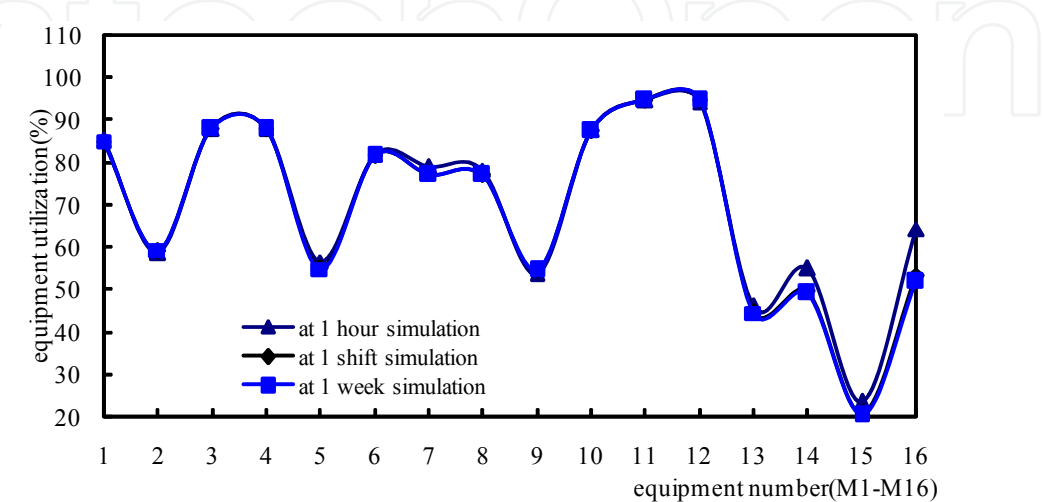
Fig. 4.14. Equipment utilization at different simulation time
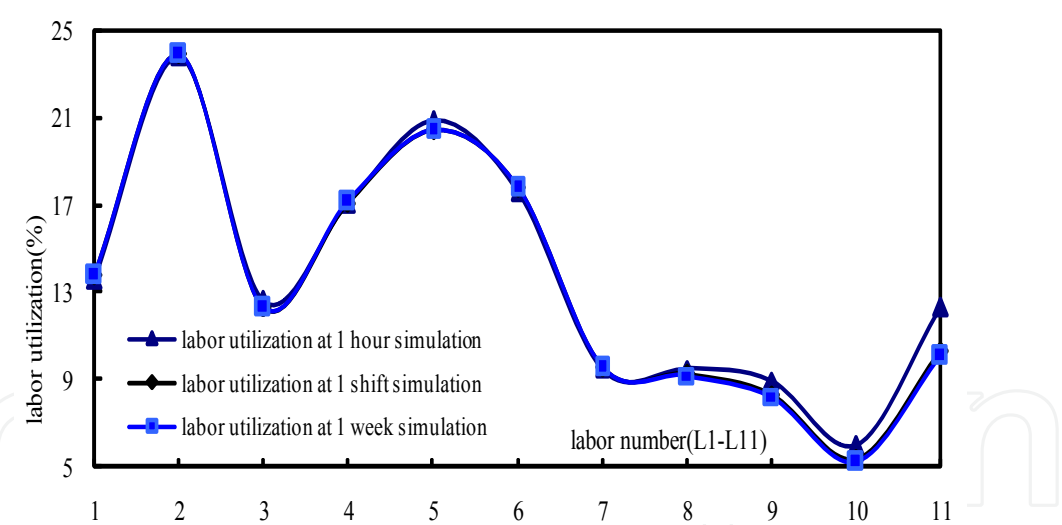
Fig. 4.15. Labor utilization at different simulation time

4.   Utilizations of labor

Labor utilizations are shown in the labor intensity during the piston manufacturing. The utilization of each labor at different times after the simulation data is shown in Fig. 4.15.

Fig. 4.15 shows: labor utilization of L2 (responsible for finishing turning iron groove process) is the highest, up to 23.9%, followed by labor utilization of L5. But labor utilization of the bottleneck process operated by L7 (responsible for finishing cylindrical) is lower because the percentage of machine processing time is larger. It leads to decrease the

percentage of operating time of labor. During this condition, it is often no longer allowed this labor to operate other machines in order to guarantee machining precision of the bottleneck process. The labor utilization of L10 (responsible for the rolling of the pin-hole process) is lower. It is indicated that the labor has the capacity to operate other machines, to reduce the number of the labor.

4.3.4 Re-design of the production line

Therefore, when redesigning the piston production line, based on the bottleneck diagnosis and analysis with adjusting the process and equipment, or optimizing the layout parameters, it can reduce labor intensity, improve equipment utilization, and reduce the layout area to make the piston production line more balanced.

After re-adjusting the layout, the arrangement of the machine layout is shown in Fig. 4.16. Fig. 4.2 and fig. 4.16 show that: the layout of the optimized piston production line is more compact, which fully takes advantage of the spare station. Optimized layout area S' = 171.603m^2, and the layout area is reduced by 36.827 m^2 than that of before optimization.

Under the same conditions (the same process, the same operating frequency and other parameters) walking paths before and after the optimization are shown in Figure 4.17, it is indicated that: the optimized walking distance of the workers have been shortened at different degree, and the machine arrangement is more compact as well as operating range of the workers is more reasonable. Before and after optimization in this production line, significantly shorter walking paths are: L3 (responsible for finishing turning aluminum tank), L4 (responsible for semi-finishing boring pin hole process), L8 (responsible for the fine turning roof surface process), because the layout optimization is mainly carried out on the machines that they are responsible for it.
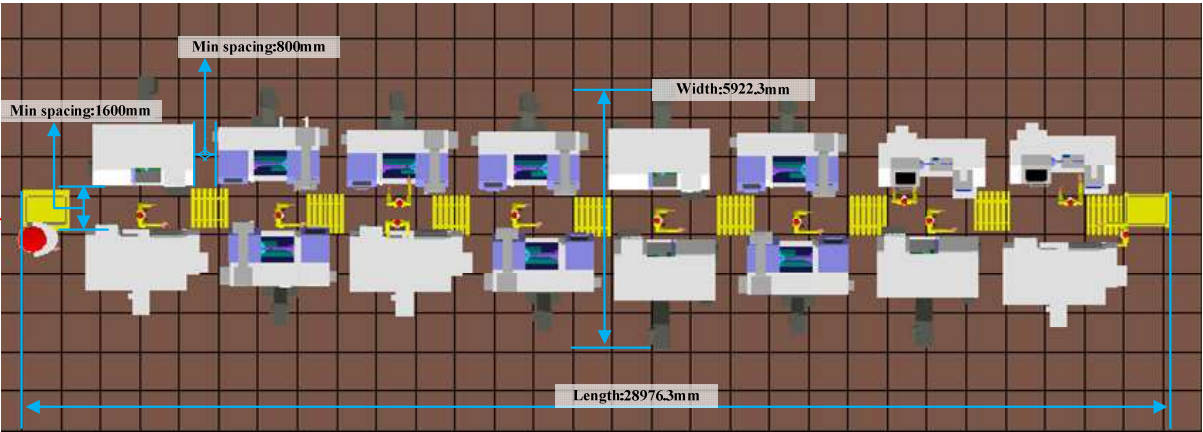

Fig. 4.16. Virtual layout after optimization

Through the analysis for the cycle time, the balance of the process time, utilizations of machines and labors, the most serious bottleneck process in this production line are fine turning of cylindrical, followed by rough and fine turning of the combustion chamber. But the production line's performance is improved evidently, after taking those optimization measures as following:

1. Improve the feed of finishing turning of cylindrical. Increasing the feed of finishing cylindrical to 0.12mm / r, the process can save time 22.7s.

2. Combine the fine and rough turning of the combustion chamber to reduce the auxiliary time, the process can save 9.5s. At this time, the process time of the fine and rough turning of the combustion chamber is 72.06s, but the process needs two devices.
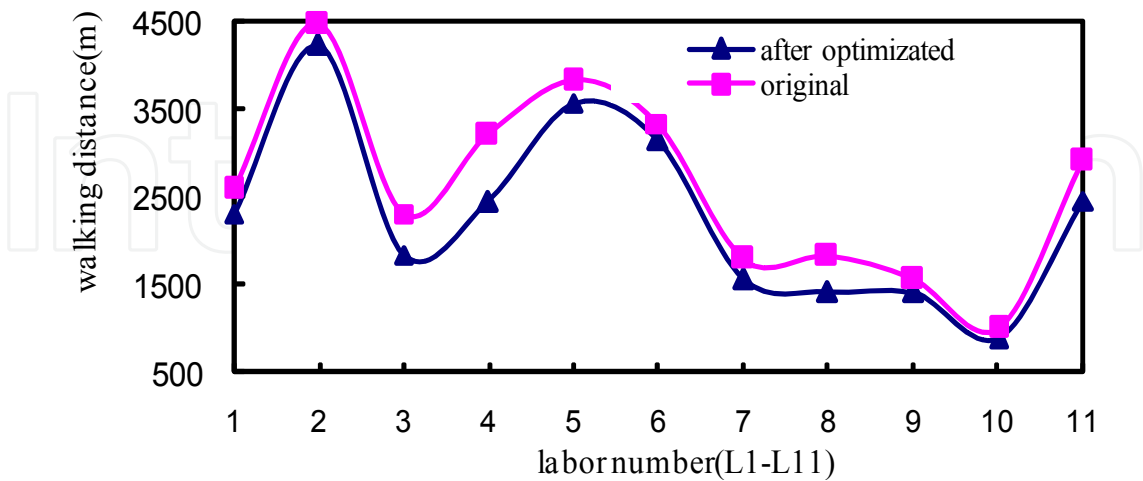

Fig. 4.17. Walking distance of labors before and after optimization

Through above methods, it is modified the virtual dynamic logic model, and simulated the redesign model again, the results could be gained, the piston production per shift in this piston production line increase from 336 to 516, and the most serious bottleneck processes have been weakened. Figure 4.18 and 4.19 show respectively the machine utilization and labor utilization before and after eliminating the bottleneck. It is indicated that: after taking the bottleneck reducing measures, the machine and labor utilization of each process after the bottleneck is improved, reduces the utilizations of machine and labor before the bottleneck to reduce bottlenecks by making the production line in balance direction.
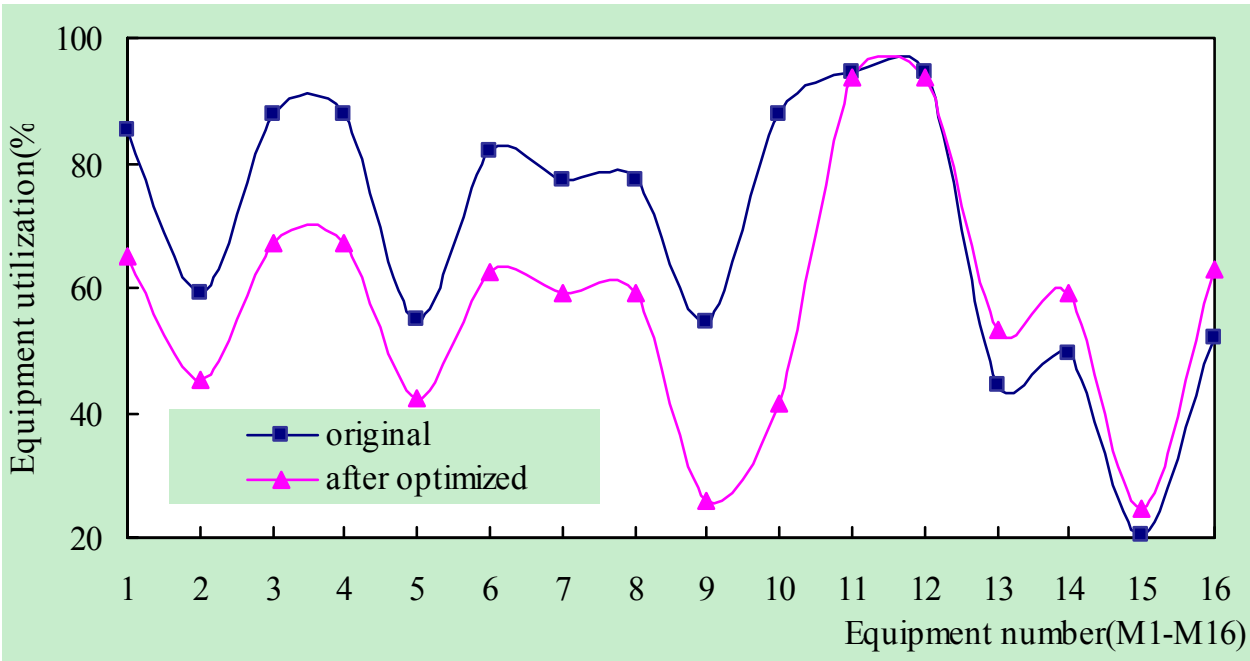

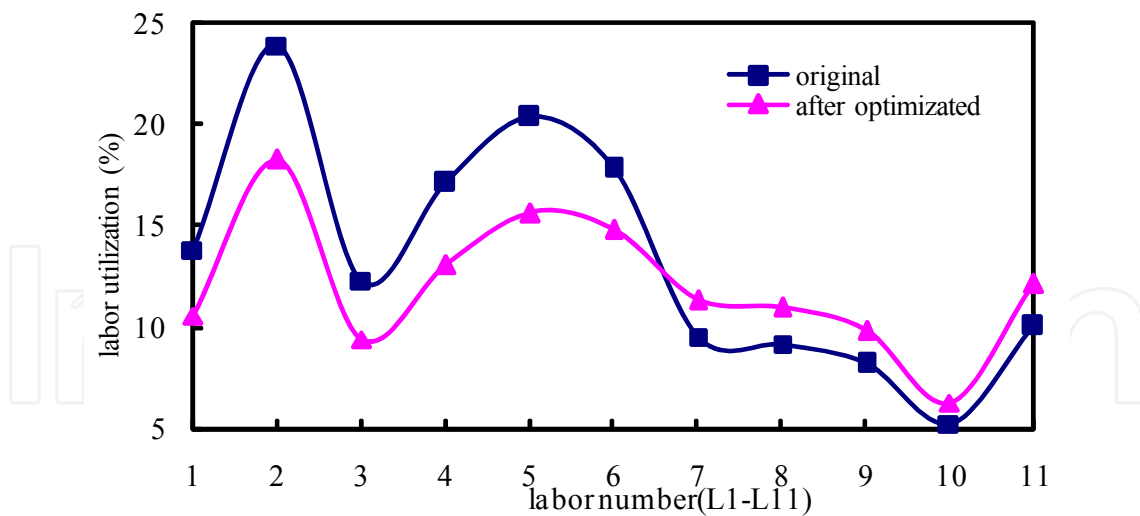Fig. 4.18. Utilizations of machine tool before and after optimized

Fig. 4.19. Utilizations of labor before and after optimized

5. Conclusions

Compared to the traditional design method of the production line, virtual design of the production line integrates many advanced technologies, and applies the unified manufacturing process modeling, analysis and dynamic optimization and other advanced design tools to get multiple-objective optimal results. Meanwhile, it is easier to get corresponding design data and decision-making data. Based on those simulation results, it can gain some methods quickly to redesign the real production line's parameters in the early design stage. So, this design method is a prospective powerful tool for the manufacturing planning.

With object-oriented technology, combined with the advantages of QUEST and UML, it is established the simulation model of the piston production line mapping from real to virtual environment with UML class diagram of the physical equipment, process, logic control and system interaction classes. The virtual model of this production line is divided to steps: static modeling is described with the hierarchy of various resources objects in piston production line and other static characteristics, and dynamic modeling defined with behavioral and control logic processes.

With this virtual design method, an instance of this piston production line is used to not only present the virtual design procedure, but also compare those design results quickly with the virtual model. From those simulation results, it is shown that the optimized production line can greatly reduce the labor intensity, improves equipment utilization, decreases the layout area, and makes all processes more balanced. With this method, all design procedures are achieved in a virtual environment with a short design cycle before carrying out the real production line. It is easy to avoid wasting the resource and making the system design more reliable and effective during the beginning planning for the piston production line, which can save the design cost and time to improve the design performance success.

6. References

Da Silveira, G., Borenstein, D.&Fogliatto, F.S.(2001). Mass customization. *International Journal of Production Economics*, Vol.72,No.1, (June 2001),pp.1–13. ISSN 0925-5273

Dirk Rantzau et al..(1999).Industrial virtual reality engineering applications, *The Symposium on Industrial virtual Reality and the 1999 ASME Mechanical Engineering Congress and Exposition (IMECE'99)*, Vol. 5, pp. 49-56 ,Chicago, USA. 1999.

Ford, H., (1926). *Today and Tomorrow (special reprint,1988).* Productivity Press, ISBN-100915299364 ISBN-13 978-091-5299-36-2, Cambridge.

FAN Xiu-min et al.(2001).Research & Application of Simulation & Optimization Technologies in Virtual Product Manufacturing Planning.*Computer Integrated Manufacturing Systems-CIMS*,Vol.7,No.8(August 2001), pp.41-43,ISSN 1006-5911

F.T.S. Chan, H.K. Chan.(2004).A comprehensive survey and future trend of simulation study on FMS scheduling, *Journal of Intelligent Manufacturing*,Vol.15,No.1,pp.87–102. ISSN 0956-5515

GAO Chonghui et al.(2010).Research and application of virtual simulation of automatic press line for automobile panel. *Forging &Stamping Technology*, Vol.35,No.1(January 2010),pp.146-148,ISSN 1000-3940

H.T. Papadopolous, C. Heavey, J. Browne.(1993).*Queuing theory in manufacturing systems analysis and design* Chapman & Hall. ISBN 978-041-2387-20-3

J.S. Smith.(2003).Survey on the use of simulation for manufacturing system design and operation, *Journal of Manufacturing Systems*,Vol.22,No.2 (March 2004),pp.157–171, ISSN 0278-6125

Kotler, P.(1989). From mass marketing to mass customization. *Planning Review* 17(5), 10–13.

Lee, H., Peleg, B.&Whang, S.(2005).*Toyota: Demand Chain Management*. Harvard Business School Publishing, Boston, MA, Case No.GS-42.

M.J. Ashworth, K.M. Carley.(2007).Can tools help unify organization theory? Perspectives on the state of computational modeling, *Computational and Mathematical Organization Theory*,Vol.13 ,No.1(August 2006),pp.89–111,ISSN 1381-298X

Par Klingstam, Per Gullander.(1999).Overview of simulation tools for computer-aided production engineering *Computers in Industry*. Vol.38,pp.173-186,ISSN: 0166-3615

S.H. Han, et al.. (2012). Automated post-simulation visualization of modular building production assembly line, .*Automation in Construction*. Vol.21, pp.229-236,ISSN:0926-5805.

Shao Li et al.(2000). Virtual integrated design of production line. *Industrial engineering and management*, No.6(June 2000),pp.1-4,ISSN 1006-5429

S B Yoo et al.(1994).An Object-Oriented approach to integrated control of flexible manufacturing systems.*International Symposium on Advances in Intelligent Computer Integrated Manufacturing System*.No.1,pp.383-386

S.M. Shafer, T.L. Smunt.(2004).Empirical simulation studies in operations management: Context, trends, and research opportunities, *Journal of Operations Management*,Vol.22,No.4 (August 2004),pp.345–354, ISSN: 0272-6963

Thomas Volling , Thomas S. Spengler.(2011).Modeling and simulation of order-driven planning policies in build-to-order automobile production. *International Journal of Production Economics*, Vol.131,No.1 (May 2011),pp.183–193. ISSN 0925-5273

T.S. Baines, D.K. Harrison.(1999).Opportunity for system dynamics in manufacturing system modeling, *Production Planning and Control*,Vol.10,No.6 (1999),pp.542–552.

Yong-Sik Kim, Jeongsam Yang&Soonhung Han.(2006).A multichannel visualization module for virtual manufacturing.*Computers in Industry*,Vol.57,No.7 (September 2006),pp.653–662,ISSN 0166-3615

Zhao Ji et al.(2000).On Implementing Virtual Production Line. *Journal of Northwestern Polytechnical University*, Vol.18,No.4(April 2000),pp.518-521,ISSN 1007-5429

Zhang Longxiang.(2007)*UML and System Analysis and Design(2nd edition)*. Post & Telecom Press, BeiJing, ISBN 978-711-5159-52-6
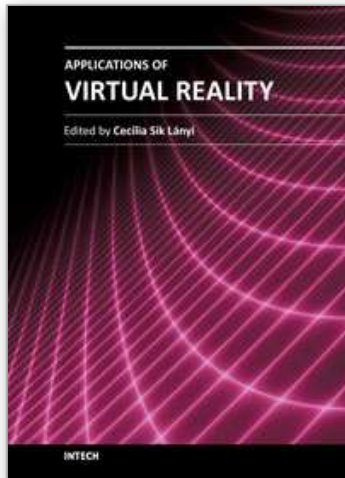
Applications of Virtual Reality

Edited by Dr. Cecília Sík Lányi

Information Technology is growing rapidly. With the birth of high-resolution graphics, high-speed computing and user interaction devices Virtual Reality has emerged as a major new technology in the mid 90es, last century. Virtual Reality technology is currently used in a broad range of applications. The best known are games, movies, simulations, therapy. From a manufacturing standpoint, there are some attractive applications including training, education, collaborative work and learning. This book provides an up-to-date discussion of the current research in Virtual Reality and its applications. It describes the current Virtual Reality state-of-the-art and points out many areas where there is still work to be done. We have chosen certain areas to cover in this book, which we believe will have potential significant impact on Virtual Reality and its applications. This book provides a definitive resource for wide variety of people including academicians, designers, developers, educators, engineers, practitioners, researchers, and graduate students.

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