Design and Kaizen of Automated Assembly Production Lines Using 3D Computer Graphics

Masatoshi Kitaoka, Toshio Fujita and Hideki Kumagai
Department of Industrial Engineering
Kanagawa University, Rokakubashi, Yokohama 221-8686 Japan

Hitoshi Takeda
Department of Information Management
Bunkyo University, Chigasaki, Kanagawa 253-8550 Japan

Abstract

This paper proposed the design method for an automated assembly lines, for carrying out basic design using three-dimensional computer graphics (3DCG).It also proposes a method for performing kaizen and evaluation of automated systems utilizing hierarchic structure diagrams, state transition diagrams, improved tooling flow diagrams, a method for creating a Ladder Logic Diagram(LLD).Using a time Petri net, analyze the bottleneck process, identify problem points, and propose ideas for kaizen.

Keywords

Kaizen,three-dimensional computer graphics (3DCG),timed Petri net, hierarchic structure diagrams, ladder diagrams, and AHP

1. Introduction

At present most production shop floors in Japan, while becoming more technically sophisticated, are being automated to boost productivity, reduce labor costs, and so forth. In the area of assembly work, too, there is increased use of automation utilizing mechatronics or robots. Simulation is an indispensable technique for designing and building optimal automated systems. Building an automated system using actual machinery, in addition torequiring a lot of equipment, necessitates overcoming various technical difficulties, as well as securing the requisite energy and physical space. It also takes time and incurs costs. For these reasons, there needs to be a way of building an automated production line that affords easy system control, taking such things as line balance and work time into account. In addition, reducing production costs through kaizen of existing automated systems is becoming increasingly important. Kaizen means continuous improvement, and therefore the philosophy of kaizen is both the starting point and the driver for all lean manufacturing initiatives. The kaizen program is designed to help companies create a solid foundation for change, allowing acceptance and effective integration and thereby enabling a company to sustain the process improvements and realize the positive financial and cultural outcomes [1,2]. The simulator of Arena and AutoMod are not correspond the command of PLC and the cost is expensive. The small enterprise is difficult to adopt the simulator system. In the area of designing automated assembly lines, the present study proposes a method for carrying out basic design using three-dimensional computer graphics (3DCG) by input the ladder diagram; it also proposes a method for performing kaizen and evaluation of automated systems utilizing hierarchic structure diagrams, state transition diagrams, improved tooling flow diagrams, a method for creating a Lower Limit of Detection (LLD), time Petri net, and AHP. The cost is cheap for developed system.

2. Procedure for Constructing an Automated System

2.1 Procedure for an Automated System

For this study, we will construct an automated production system for making music boxes. The method we are proposing for constructing an automated system is as follows.

Step 1: Make an actual production plan, and describe the music box production flow using work process diagrams.

Step 2: Consider the system makeup for each process, based on the work process diagram and individual process diagram.

Step 3: Actually construct the system in a 3DCG space that uses virtual reality modeling language (VRML).

Step 4: Describing the operations of each system using hierarchic structure diagrams, create an LLD using state transition and functional tooling flow diagrams.

Step 5: Based on the LLD, create an animation program for VRML and perform simulation in 3DCG space.

Step 6: Calculate the line balance from the simulation results.

Step 7: Using a time Petri net, analyze the bottleneck processes, identify problem points, and propose ideas for kaizen.

Step 8: Break down the proposed kaizen using AHP, and indicate the most suitable kaizen proposal.

2.2 Construction of an Assembly Process

The main body of a music box is made up of a vibrating plate and two screws; construction is completed once the vibrating plate is attached with screws to the main body. The production equipment is designed based on a production plan. It specifies the following: operation time of 420 minutes, production volume of 800 pieces, downtime of 30 minutes, defect rate of 1%. Using work process diagrams to display the production flow, it becomes clear that there are three processes for supplying the parts, there is one assembly process, and there is one process for product collection, for a total of five processes. For each process, we create a system makeup diagram, determine the equipment necessary to build the system, and create a system layout. The specific work content is as follows. In Process 1, a robot arm is used to supply the music box main body to a designated location on a pallet. In Proce2, a handling robot and crank mechanism are used to supply the music box vibrating plate to a designated location on the pallet. In Process 3, a handling robot and twisting mechanism are used to supply two screws from a feeder to a designated location on the pallet. In Process 4, the music box vibrating plate is moved to a fixed location in the main body, a driver unit is used to tighten the screws, and the vibrating plate is secured in place. In Process 5, a robot arm is used to collect the finished product. It should be noted that Processes 1 and 5 use the same robot arm; and because work is conducted in a seamless manner, these two processes are performed at the same work station. For this reason, the production line is made up of four work stations, identified as Stations 1 through 4[3-5].

2.3 Actualization of an automated line in virtual space using 3DCG

The automated system have constructed in virtual space by means of 3DCG employing VRML language. VRML is a computer graphics description language that was developed with the purpose of representing 3DCG with Internet and PC applications in mind. Linking it with programming languages such as Java and Java Script makes it possible to represent complex movements.

2.4 Constructing a system with VRML

To actually construct a system with 3DCG, each of the different types of modules is first created in separate spaces, and these modules are then placed in a subspace. For example, in the system for automated supply of the vibrating plate in Station 2, each station is realized by creating a module for each piece of equipment, and placing these in Subspace 2 in each station based on the system makeup diagram. An entire production system is created by reproducing each operation system in each subspace, and then placing these in the primary space. Figure 1 shows the structure of primary space, subspace and modules.

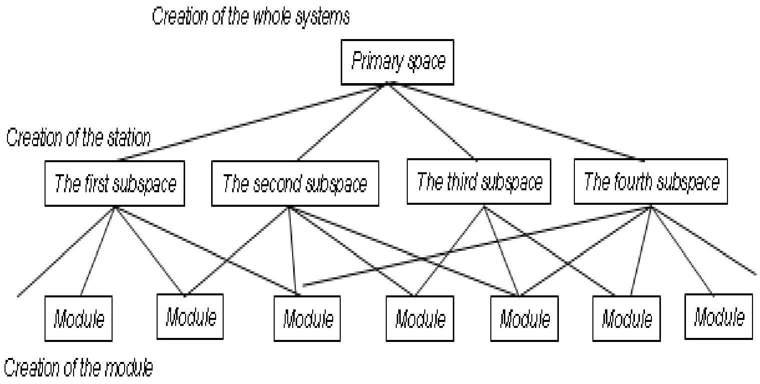


Figure 1: Primary space, subspace and module

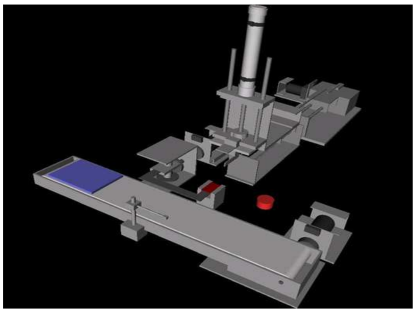


Figure 2: An automated subsystems by VRML

2.5 3DCG control methods

VRML 2.0 comes with animation functions to change location, rotate, and reduce in size. As a means of controlling 3DCG animation, we will create programs with timer and location detection functions. By means of these two functions, it becomes possible to freely control straight line and rotational movement, which are basic operations in each. Further, when this is combined with Java/JavaScript, it becomes possible to set such parameters as contact judgment and priority of movement. By using these functions, we can perform a movement simulation in 3DCG using the same control methods as are used in an actual PLC. Because it is necessary to make the movement of each module equivalent to that of the actual equipment, we will set the movement range, contact judgment, movement speed, etc., in advance. In an actual system, the equipment is controlled using LLD. For that reason, we analyze the necessary movement for each station and create the LLD. We create the LLD by using three diagrams - the hierarchic structure diagram, state transition diagram, functional tooling flow diagram. Next, to control the 3D simulation with the LLD, we create a program that converts the LLD into a VRML control program.

2.5.1 Creation of a hierarchic tool structure diagram

To express the system structure in a hierarchic manner, we create a hierarchic tooling structure diagram as shown in Figure 3. The hierarchic tooling structure diagram has a 4-tiered structure as follows. Level 1 shows the overall system structure. Level 2 shows a partial structure of the system. Level 3 shows the operation of a part of the system in general terms. And Level 4 shows machine operation and other system elements in minute detail.

2.5.2 Creation of a state transition diagram from the hierarchic tooling structure

To make the state transition of the system easier to understand, and facilitate the creation of the LLD, we create a state transition diagram. The state transition diagram shows how changes in state at a particular step will change the output. We utilize Level 4 of the hierarchic tooling structure diagram from Figure 3 to create the state transition diagram, as shown in Figure 4. Figure 4 shows the state transition diagram [4].

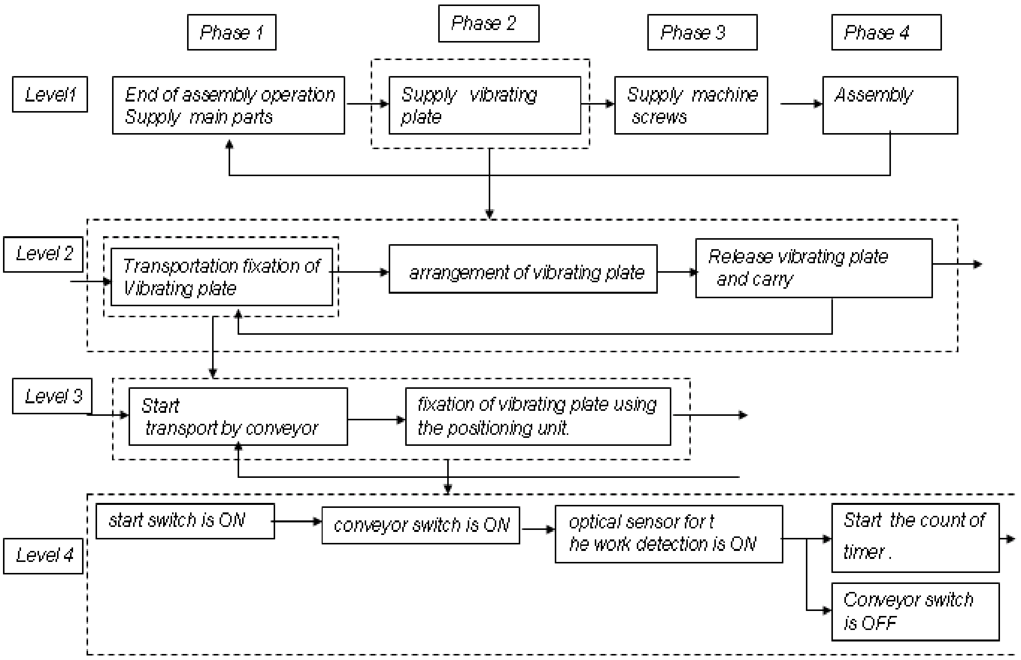

Phase 1
Phase 2
Phase 3
Phase 4
Level1
End of assembly operation Supply main parts
Supply vibrating plate
Supply machine screws
Assembly
Level 2
Transportation fixation of Vibrating plate
arrangement of vibrating plate
Release vibrating plate and carry
Level 3
Start transport by conveyor
fixation of vibrating plate using the positioning unit.
Level 4
start switch is ON
conveyor switch is ON
optical sensor for t he work detection is ON
Start the count of timer .
Conveyor switch is OFF

Figure 3: Hierarchic tool structure diagram

2.5.3 Creation of the functional tooling flow diagram from the state transition diagram

To create the LLD efficiently, based on the state transition diagram, a functional tooling flow diagram is created shown in Figure 5 based on the state transition diagram. The procedure is as follows.

Step 1: Make sure there are five rows: input (X), counter (C), internal relay (M), timer (T), and output (Y).

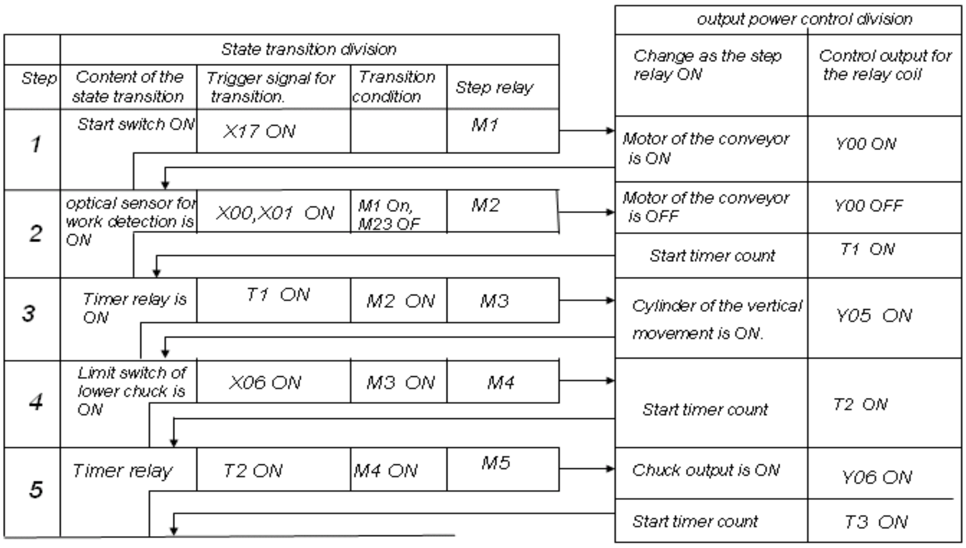
Step 2: Line up STEP relays from M1 to Row M all the way to the final STEP.

Step 3: Connect one STEP relay to the next. The beginning STEP from the final STEP to the next loop is connected using a red arrow.

Step 4: Assign one of the rows X, C, or T as the input symbol to STEP relay M001, and connect. At this time, the OFF symbol will be connected in red.

Step 5: Assign a control output to STEP relay M001, and connect. At this time, the OFF symbol will be connected in blue.

Step 6: Repeat until the final STEP is reached.



	State transition division				output power control division	
Step	Content of the state transition	Trigger signal for transition.	Transition condition	Step relay	Change as the step relay ON	Control output for the relay coil
1	Start switch ON	X17 ON		M1	Motor of the conveyor is ON	Y00 ON
2	optical sensor for work detection is ON	X00,X01 ON	M1 On, M23 OF	M2	Motor of the conveyor is OFF	Y00 OFF
					Start timer count	T1 ON
3	Timer relay is ON	T1 ON	M2 ON	M3	Cylinder of the vertical movement is ON.	Y05 ON
4	Limit switch of lower chuck is ON	X06 ON	M3 ON	M4	Start timer count	T2 ON
5	Timer relay	T2 ON	M4 ON	M5	Chuck output is ON	Y06 ON
					Start timer count	T3 ON

Figure 4: State transition diagram

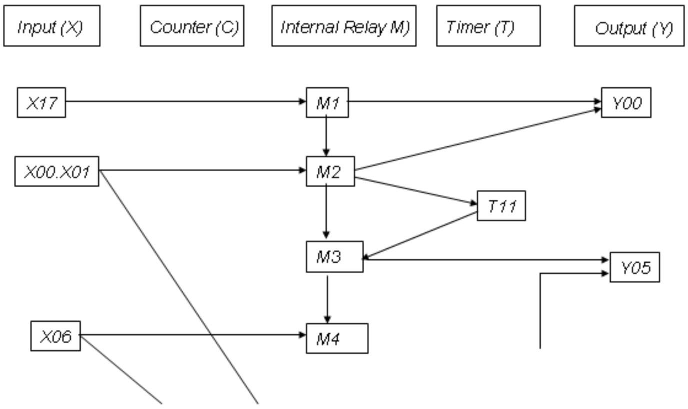


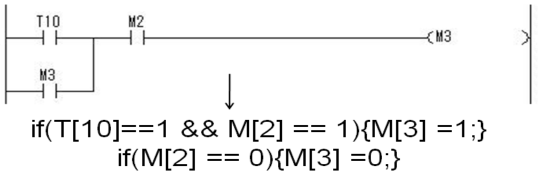
Figure 5: Functional tooling flow diagram

2.5.4 Converting from functional tooling flow diagram to LLD

Step 1: Determine the STEP relay output. The STEP relay Mα will take the “OR” for input signal and STEP Mα, and “AND” for input STEP relay. Step 2: Next, set up the output. To the output take “OR” from the ON signal for the STEP relay, the initial “OFF” signal and “AND.” Treat this as one set, and connect an “OR” to each set. Step 3: Lastly, set the timer. To each timer designate an input STEP relay, and set to the desired time.

2.5.5 Animation program

Based on the LLD that has been created, we create a VRML animation program. However, because in the ordinary method of creating animation it is necessary to set “time” and “motion” in advance, simulation of motion is very difficult. However, we made control of the simulation and LLD possible by adding a script that continuously and instantaneously rewrites the object coordinates, and by using these coordinates as a sensor. Fig6 shows the procedure of the LLD convert into JAVA script.



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if(T[10]==1 && M[2] == 1){M[3] =1;}
if(M[2] == 0){M[3] =0;}
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Figure 6: Procedure of LLD convert into VRML

2.6 Simulation Results

We constructed all stations from Station 1 to Station 4, and also created the animation program. Integrating these in the primary space completes the virtual music box production system. The results of performing simulations with this virtual system and measuring operation times are shown in Table 1. It should be noted that the work time for Station 1 is the total of the work times for Process 1 and Process 5.

Table 1: Simulation result (Sec)

Station Number	1	2	3	4
Work time	28.6	27.2	70.9	27.7

2.7 Line balance

From the initial production plan, we calculate the pitch time, which is the standard work time per one product unit. Unless the work time of each process is at least lower than this value, it will not be possible to accomplish the production plan. Also, in a line production system for performing flow work of the kind in this system, it is vital that the work time of each process be equalized and stabilized insofar as possible. However, because the work time of each process differs depending on the content of that work, there will be some variation. For that reason, the work time of the bottleneck process becomes the standard for the work time of the entire system; in systems with processes that are performed more quickly, some wait time will result. The more wait time there is, the more the work efficiency declines. For this reason, to ensure that the difference in work time between different processes is as small as possible, it is necessary to design the line so that the work time of each process is below but close to the pitch time. The line composition efficiency expressing balance of work times for all processes is found by Formula (1). The line composition efficiency of this system is 54.4%. Normally, a line balance efficiency rate of 90% or higher is considered ideal, and a rate of at least 75% is required. Also, in the designed system, the work times of Stations 1, 2 and 4 are below the pitch time, and are also very close to the work time. However, the work time of Station 3 is far higher than the pitch time. As a result, system kaizen is required.

2.8 Producing kaizen proposals using a time Petri net

The work kaizen of Station 3 is the bottleneck process. First of all, we express the work of Station 3 in a time Petri net, as shown in Figure 7, and perform analysis. Also, we identify any problem points that can be visually gleaned from the VRML simulation. The result is that the following problems are found to exist: Most operations are performed serially, and this is not efficient. (2)Because a single feeder supplies 2 parts, time is wasted going back and forth. (3)Because a feed screw mechanism is used for the back-and-forth movement, it is extremely slow. To resolve these problems, the following kaizen are proposed:

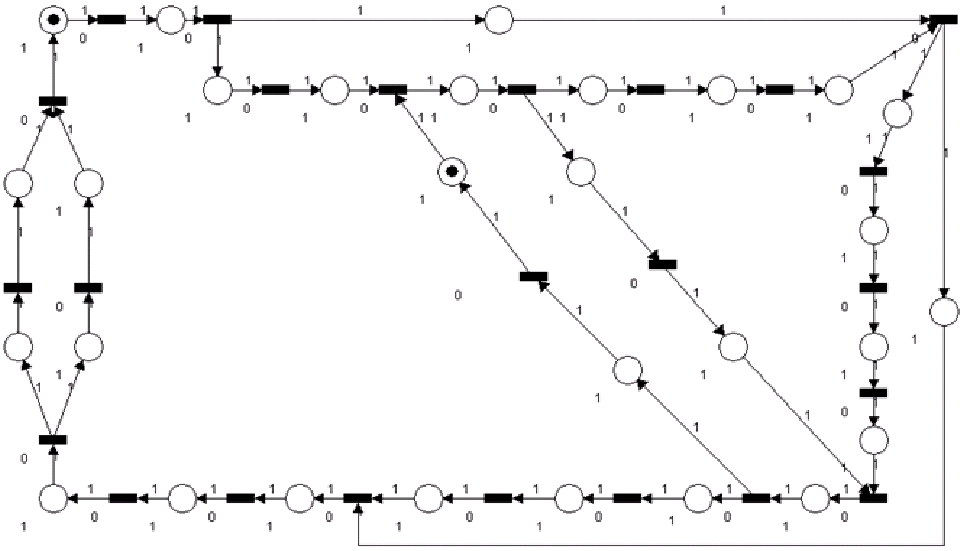

Figure 7: Time Petri net for station 3

(1) Change the LLD based on the Petri net results so that operations can be conducted in parallel in areas where parallel operation is possible. (2)Make the feeder a double track, so that 2 parts can be supplied at the same time. (3)Increase the speed of the feed screw mechanism by putting in a more powerful motor. As a result of implementing the above kaizen, the Station 3 work time and the system line balance efficiency shown in Table 2 was achieved.

Table 2: Result of kaizen

Content of kaizen	Line balance efficiency (%)	Work time (Sec)
Present production process	54	70.9
a) Improvement on the program	60	59.3
b) Change the speed of motor	72	44.8
c) Parts feeder route is increased at 2line.	91	31.4
d) b + c (Motor + feeder)	95	25.3

2.9 AHP analysis of kaizen results

Kaizen of the system work time naturally had the positive effects of shortening work time and improving line balance efficiency. But these kaizen may also result in the negative effects of increased costs and reduced reliability. So each kaizen proposal is analyzed with AHP using the pair comparison method, and the question of whether each kaizen should be adopted is studied.

2.9.1 Analysis of kaizen results

The kaizen results actually obtained are then broken down as follows into a hierarchic structure. Note: in this study, line balance efficiency, cost, defect rate, and downtime rate were used as the judgment items. 1)Final target: Optimum kaizen proposal.2)Judgment target: Line balance efficiency, cost, defect rate, downtime rate 3)Alternative proposals: ① perform kaizen by rewriting LLD, ② replace motor, ③ replace part supply device, and ④ replace both motor and part supply device. Next, perform a pair comparison of each judgment item. Since in this instance the objective is to kaizen the line balance efficiency, priority was placed on this item. Finally, compare the alternative proposals in terms of each judgment standard. From the standpoint of line balance efficiency, replacing the motor and replacing the part supply device, which had the largest impact, were emphasized. Whereas from the standpoint of cost, downtime rate, and defect rate, the emphasis was on kaizen that entailed smaller changes.

2.9.2 AHP Result Analysis and simulation

Carrying out the pair comparison according to the above rules yielded the evaluation values shown in Table 3. According to Table 3, replacing the motor and the part feeder are the optimum kaizen.

Table 3: Overall Evaluation Values

Alternative proposals	Kaizen by rewriting the LLD	Replace motor	Replace part supply mechanism	Replace both motor and part supply mechanism
Evaluation value	21.7	13.1	24.5	40.7

Using the virtual music box production system, the kaizen items are verified by computer. The kaizen of replacing the motor and the part feeder mechanism that were identified by AHP are implemented on Station 3. The results of these kaizen are reproduced using the animation program. The results of performing operation simulation and measuring work times are shown in Table 3.

3. Conclusion

We proposed a method for reproducing product assembly order and assembly process in 3DCG space using VRML, and for controlling this using LLD. Using hierarchic structure diagrams, state transition diagrams, and improved tooling flow diagrams, we established a method for supporting LLD creation. This has made it possible to easily and reliably create an LLD. To improve the overall efficiency of the automated system, we used a time Petri net to propose kaizen, made a comparison of these kaizen using AHP, and decided on the kaizen proposals that met our stated objectives. The following are some of the merits of running simulations in 3DCG space using VRML: (1) Because the system can actually be viewed, one can easily get a sense of how it will look upon completion. (2)Problem points can be grasped on an intuitive level. (3)Using LLD in combination with time Petri net makes it easy to prepare many alternative modules, and to propose kaizen. The cost is cheap for developed system. Therefore, it can apply even in the small-scale enterprise.

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