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A Proposal for Prototype-Free Production Preparation Processes Utilizing 3DCG Animations

Shinji Shinoda†
Department of Industrial Administration
Tokyo University of Science, Chiba, 278-8510, JAPAN
Tel: +81-4-7124-1501 Ext.3829, Fax: +81-4-7122-4566, E-mail: shinoda@ia.noda.tus.ac.jp

Kazuhiro Shimozawa
Product Quality Management Quality Assurance Group
Fuji Xerox Co.,Ltd, Kanagawa, 243-0494, JAPAN
Tel: +81-46-238-3112→513446(Direct), Fax: +81-46-238-6650, E-mail: Shimozawa.Kazuhiro@fujixerox.co.jp

Akira Niwa
Department of Electromechanics Seikei University Tokyo, 180-8633, JAPAN
Tel: +81-422-37-3763, Fax: +81-422-37-3871, E-mail: niwa@st.seikei.ac.jp

Takeshi Kawase
G.N.N Co.Ltd, Tokyo, 107-0052, JAPAN
Tel: +81-44-966-7129, Fax: +81-44-954-2922, E-mail: kawasetk@gnn-inc.co.jp

Toshiyuki Matsumoto
Department of Industrial and Systems Engineering
Aoyama Gakuin University, Kanagawa, 229-8558, JAPAN
Tel: +81-42-759-6304, Fax: +81-42-759-6556, E-mail: matsumoto@ise.aoyama.ac.jp

Tadahiro Mizumachi
Department of Electromechanics
Seikei University, Tokyo 180-8633, JAPAN
Tel:+81-422-37-3772, Fax:+81-422-37-3871, E-mail: mizumachi@st.seikei.ac.jp

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Abstract. As the use of 3DCAD data became widespread in designing products in manufacturing, attempts have been made to shorten lead time and reduce cost of production preparation utilizing 3DCAD data for launching assembly lines. In order to create assembly plans not only efficient but easy for operators to operate ('easy-to-operate'), this study presents approaches, methods, and systems for creating 3DCGAs (3 Dimensional Computer Graphic Animations) which automatically utilize a prototype-free production preparation methodology. Characteristics of this study include that it proposes the methodology for creating assembly operation 3DCGAs automatically, for all the possible assembly operations corresponding each of the possible assembly sequences first. Using the created 3DCGAs, the study next considers assembly methods by evaluating how easy or 'operator friendly' they are in implementing, and devises tools or jigs to be used, and plans efficient assembly line organization. The concept of the methodology was formed by focusing on the value-adding assembly steps at which parts turn into products directly. The study also validates the effectiveness of the presented methodology by employing the methods used in actual production preparation process in businesses, and proves that an efficient assembly line can be organized in a shorter period of time utilizing the developed system and by preparing easy-to-operate and efficient plans in 3DCGAs at the design stage.

Keywords: Prototype-Free Production, 3DCG, Production Preparation, 3DCAD, Assembly, Virtual Factory

† : Corresponding Author

1. INTRODUCTION

As an increasing number of drawings for product design are currently produced in 3DCAD, it is now possible for the production preparation department to acquire digital information of products at the design stage in the field of product manufacturing. This transition may bring major changes to activities of conventional production preparation conducted up until now(Chen *et al.*, 2002; Grieves, M. 2006; Molina *et al.*, 1995; YIN Z-P. 2004). In the conventional preparations, process flows were established through the use and examination of prototypes, whereas the use of 3DCAD promotes direct process planning utilizing products' digital information.

Figure 1 shows the conventional preparation process of production, as well as an ideal state of future preparation process of Company X. In the conventional process, drawings for trial production are produced based on the 3D models at the design stage. At the prototype evaluation stage, actual prototypes are produced first, and after assembly, the prototypes are evaluated and design changes or alterations are discussed. Production Preparation department then uses the prototypes for considering what is referred to as 4M2S (Material, Man, Machine, Method, Space and System) in order to prepare for mass production (Figure 1(a)). With the conventional process, however, several prototypes may be produced and their evaluations must be conducted, as design changes occur or as problems for mass production are detected. Naturally, this affects the lead time and the cost of production. The study thus aims to complete production preparation based on 3DCAD data without any use or production of prototypes, resulting in shorter lead time and reduced production preparation cost (Shinji *et al.*, 2003) (Figure 1(b)).

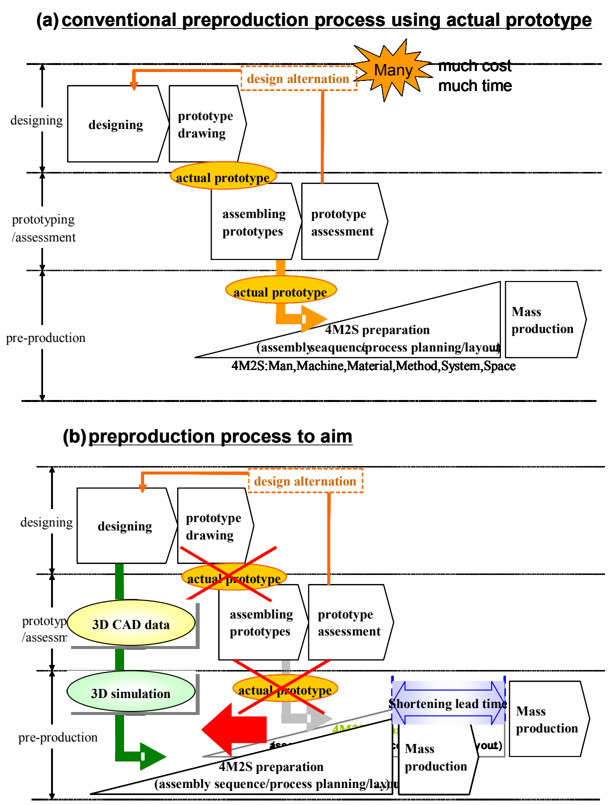

Figure 1. Conventional preparation process of Company X and Ideal preparation process.

Meanwhile, the authors have been working on researches in which 3DCGAs (3 Dimensional Computer Graphic Animations), are created automatically utilizing 3DCAD of the products (Shinji and Akira, 2000~2003; Shinji *et al.*, 2002~2003; Shinji and Akira, 2004~ 2005). The 3DCGAs are to be created for each possible assembly sequence, thus the number of 3DCGAs is equivalent to that of assembly sequences. The outline of creation methods are explained in STEP1 of Chapter3 with some references indicated. The results of the authors' earlier studies are summarized in two features below.

① 3DCGs of Assembly Operations Created Automatically from 3DCAD Data

In general, it takes a lot of time and effort to create 3DCGAs of assembly operations. This is because the necessary positional information to have computer manikins (representing assembly workers) make motions has been either manually input using computer mouse devices or transferred through motion capture devises conventionally (Figure 2). PLP does not require such time-consuming effort, since it can automatically collect necessary information for planning assembly operations from the 3DCAD data, as described in authors' preceding studies. Figure 2 shows an example of the 3DCGAs developed and created for Company X (Shinji and Akira, 2000~2003; Shinji *et al.*, 2002~2003; Shinji and Akira, 2004~2005). The detailed procedure of how 3DCGAs are created will be explained in Chapter 3, STEP1.

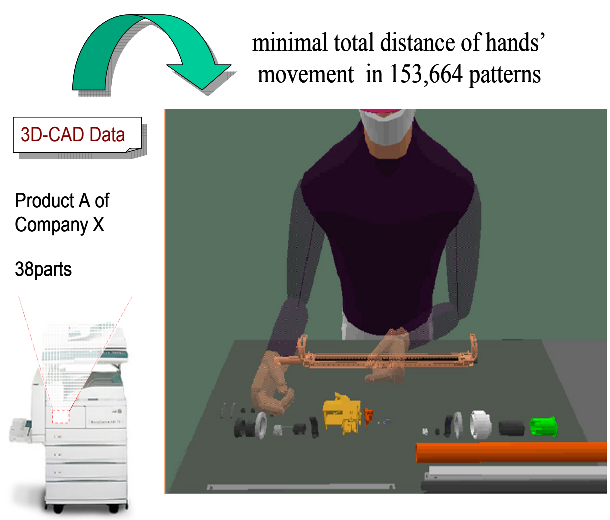

Figure 2. example of the 3DCGAs created for Company X.

② Creating an Exhaustive List of Assembly Plans Utilizing the Capacity of Computers

An assembly operation can be performed in various assembly sequences. The earlier studies demonstrated how the developed system could generate 3DCGAs for all the assembly sequences of an assembly operation, and further, evaluate the created assembly sequences objectively.

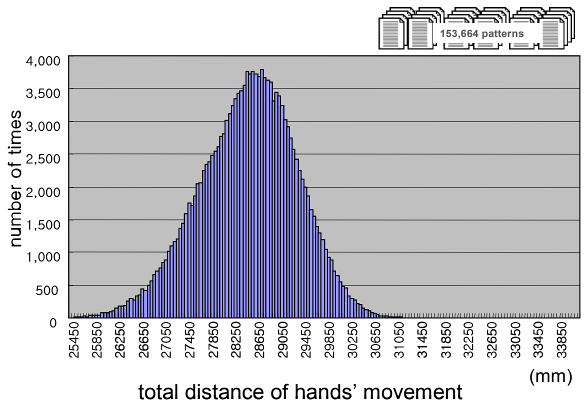

Figure 3. frequency distribution table for product assembly patterns with a product of Company X.

Figure 3 shows an example of the application of the developed system, with a product of Company X. As illustrated in Figure 2, the product consists of 38 parts; utilizing the developed system made it possible to list 153,664 assembly sequences, covering all the existing 'alternative' assembly patterns. It also enabled generating 3DCGAs for each assembly plan. The histogram in Figure 3, indicating total distance of hands' movement on the horizontal axis, and the number of times occurring in an operation on the vertical axis, demonstrates that there are a number of possible assembly sequences for an assembly operation, and that the efficiency may vary rather significantly according to each assembly sequence.

Utilizing the features of the developed system, the authors have been working on developing new prototype-free production preparation activities employing 3DCGAs (Shinji SHINODA *et al*., 2003). After actual implementation and application of the system in several business cases, the authors came to be aware that it is important to plan operations that are not only efficient but operator-friendly, and to minimize the chance of errors in operation. This is because the companies' major concern is to avoid the chances of producing defective products. Operation errors lead to clients' complaints, and for operators, it is crucial to avoid making such errors during operation, and for this purpose, efficient operations being easy to operate without undue stress are the key. However, as it may be obvious by considering differences between actual products and 3DCAD data, it has been difficult to quantify the degrees of difficulty that operators may experience in operations and reflect such difficulty in 3DCGAs. The authors believed that there must be certain differences between operations that are difficult to operate and easy to operate, and that there must be a way to present such differences as 3DCGAs. The issue is positioned as key in this study and earlier studies were summarized to introduce the fundamental features and the application process of PLP system. This study also deals with how the system was developed after applying the system in some businesses and taking new approaches, efforts have been made to find a clue to this issue.

This study thus presents a new prototype-free or 'prototype-less' production (hereinafter called 'PLP'). preparation process, which helps design operator-friendly and productive assembly lines utilizing 3DCGAs. The study describes the general concept of PLP, the methodology employed and the system. The study also deals with a PLP-applied example from Company X, taking one of their products and its production preparation as an example, and the effectiveness of PLP-applied production preparation is validated. Since the study focuses on presenting the basic concept and the flow of new production preparation activities with PLP, the details of methodology are described citing the authors' earlier studies where necessary.

2. METHODOLOGY FOR CREATING ASSEMBLY LINES UTILIZING PLP

As described previously, it is necessary that assembly lines are designed to be error-free, operator-friendly, economical and efficient. This chapter explains how such ideal assembly lines were designed quoting some simple examples.

2.1 Categorizing Operation Steps into Assembly Steps and Handling Steps

In order to create assembly lines effectively, first, operation steps in an assembly are categorized into two groups. The first group includes "assembly" steps, by which parts are assembled directly into semi-finished products or a finished product. (Hereinafter referred to as "Assembly Steps") Assembly Steps are the essential steps to complete a product using necessary parts, and are value-adding steps. The steps categorized in the other group are for handling, and this includes steps such as grasping, carrying or releasing parts. (Hereinafter referred to as "Handling Steps") Handling Steps are non-value-adding ones in terms of finishing a product and thus need to be minimized.

Figure 4 shows an example assembly flow for completing a product (ABCD), using parts A, B, C and

Contents of Assembly Operation 1) (*Where the operator is right-handed.*)

1) Grasp part A with the right hand.
2) Carry part A to the operating position with the right hand.
3) Grasp part B with the left hand.
4) Carry part B to the operating position with the left hand.
5) Assemble parts A and B with both hands to create a semi-finished product (AB).
6) Release the right hand from the semi-finished product (AB).
7) Grasp part C with the right hand.
8) Carry part C to the operating position with the right hand.
9) Assemble parts C and (AB) with both hands to create a semi-finished product (ABC).
10) Release the right hand from the semi-finished product (ABC).
11) Grasp part D with the right hand.
12) Carry part D to the operating position with the right hand.
13) Assemble part D and (ABC) with both hands to create a finished product (ABCD).
14) Release the left hand from the finished product (ABCD).
15) Carry the finished product (ABCD) to the product storage space with the right hand.
16)Put down the finished product (ABCD) with the right hand.

boldface: assembly step
other: handling step

Contents of Assembly Operation 2) (*Where the operator is right-handed.*)

1) Grasp part A with the right hand.
2) Carry part A to the operating position with the right hand.
3) Grasp part B with the left hand.
4) Carry part B to the operating position with the left hand.
5) Assemble parts A and B with both hands to create a semi-finished product (AB).
6) Release the right hand from the semi-finished product (AB).
7) Carry the semi-finished product (AB) to the storage space.
8) Put down the semi-finished product (AB) with the right hand.
9) Grasp part C with the right hand.
10) Carry part C to the operating position with the right hand.
11) Grasp part D with the left hand.
12) Carry part D to the operating position with the left hand.
13) Assemble part C and D with both hands to create a semi-finished product (CD).
14) Release the right hand from the semi-finished product (CD).
15) Grasp semi-finished product (AB) with the right hand.
16) Carry semi-finished product (AB) to the operating position with the right hand.
17) Assemble semi-finished products (AB) and (CD) with both hands and create a finished product (ABCD).
18) Release the left hand from the finished product (ABCD).
19) Carry the finished product (ABCD) to the product storage space with the right hand.
20) Put down the finished product (ABCD) with the right hand.

Figure 4. example of contents of assembly operations.

D, with two types of operation steps. In Assembly Operation 1, parts are put together in the order of A, B, C and D to finish a product. In Assembly Operation 2, two semi-finished products (AB) and (CD) are first created and these two are put together later to finish a product. In Assembly Operation 1, steps 5, 9, 13 are Assembly Steps, and the rest are Handling Steps. In Assembly Operation 2, steps 5, 13, 17 are Assembly Steps and the rest are Handling Steps.

As shown in Figure 4, both Assembly Operations 1 and 2 include 3 Assembly Steps. However, the total numbers of operation steps are 16 in Assembly Operation 1, and 20 in Assembly Operation 2. Such differences arise from differences in the sequence and contents of operations. Taking Assembly Operations 1 and 2 as an example and comparing Assembly Steps, while parts are put together one after another to one base part in Assembly Operation 1, in Assembly Operation 2, two different semi-finished products are created first, requiring temporary storage space and taking more trouble, leading to a greater number of steps in the operation. Change of orders or contents of Assembly Steps results in change in the number of Handling Steps as well as a major change in contents of assembly operations. As for the example case described in chapter 1, the 153,664 patterns of operations all consist of 37 Assembly Steps --- assembling parts one by one until 38 parts complete a finished product. It goes without saying that the difference in order of Assembly Steps may result in major difference in operators' hands moving distance.

Since Assembly Steps play a major role in changing parts into products, if there are any errors, such as loose assembly, are made in these steps, defective products result. Avoiding production of defective products requires careful examination of Assembly Steps.

From this perspective, what needs to be done to create error-free, easy-to-operate, and further, economical and efficient assembly line is to first focus solely on Assembly Steps involved, by assuring that the steps are error free and easy to operate. Next, with regards to Handling Steps, there are a number of combinations of Handling Steps to join Assembly Steps in an assembly. The differences among such Handling Steps to link Assembly Steps were clarified and analyzed in the authors' preceding studies, and the methods for selecting and planning minimized Handling Steps have also been presented (Shinji and Akira, 2001~2002). This study employs the same algorithms developed in the earlier studies to create such economical and efficient Handling Steps for connecting Assembly Steps.

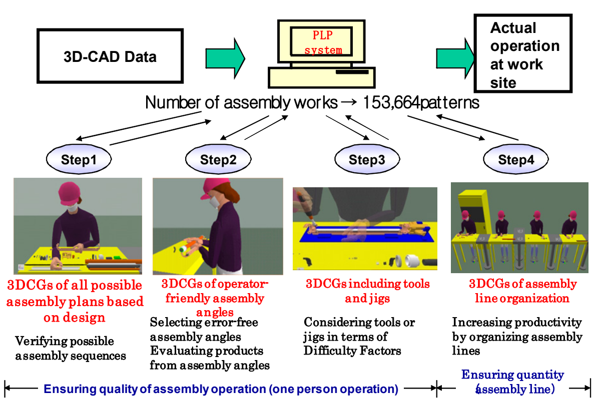

Figure 5. Considering plans using PLP.

2.2 Methodology of Assembly Line Creation Focusing on Assembly Steps of Operations

In this part, procedure of selecting and creating error-free and easy-to-operate Assembly Steps are to be discussed. First, feasible 'assembly sequences' must be clarified. This is because Assembly Steps and 'assembly sequences', through which parts are turned into finished products, are closely related, and differences in assembly orders result in differences in the number of total assembly steps in an assembly. Next, ideal assembly angles, at which assembly steps are conducted with least difficulty in assembling parts, are to be identified. There are many ways to actually assemble parts even when operators follow the same assembly sequences. When operators put parts together, they first recognize the parts to be assembled visually, in other words, using visual information of the parts, and then assemble these parts with their dominant hands. Therefore, in order to avoid making errors in assembling parts, operators must be able to visually recognize the parts and the assembly positions of the parts, and assemble parts using their dominant hands. Thirdly, at the next step in this procedure, 'Difficulty Factors' which bring operators difficulties in assembling parts at each Assembly Step, when conducting assembly at given angles, are to be clarified. Although ideal assembly angles should be clarified at the previous step, there may be cases where it is difficult to pick up parts because of their shapes, or it may be difficult to settle their assembly positions accurately. There may also be some cases where extra force is required to assemble parts. In such cases, it is more likely that operations are difficult to be carried out and operators make errors because of this. Once causes of such difficulty or 'Difficulty Factors' are identified, developing and devising tools or jigs to remove such difficulty becomes possible. Consequently, this third step includes creation of tools or jigs to remove the identified Difficulty Factors. The details of this step will be described in chapter 3, citing some of the references.

Through the three steps explained above, Assembly Steps, which are error-free, in other words, conducted with least difficulty, and thus easy-to-operate, are to be clarified. The next, fourth step of the procedure, is to consider organizing economical assembly lines to implement the Assembly Steps developed above. Using the methods proposed in the authors' preceding studies, it is possible to select Handling Steps and create assembly operations based on the contents of Assembly Steps (Shinji and Akira, 2001~2002). There are various production systems in carrying out actual operations, from one-person cell production system to conveyer assembly system performed by several operators, and to finalize efficient assembly operations, the systems that best fit the operations must be considered.

There is an exponential number of possible assembly plans, considering the number of assembly sequences, the number of possible assembly angles, the number of tools or jigs, and the number of possible production systems and lines. These plans are to be considered step by step, utilizing computers, and can be narrowed down and evaluated through examining and comparing 3DCGAs, through evaluating the contents of operations. In the conventional methods, it was difficult to detect and reduce possible errors from operators' point of view, as well as to prepare an exhaustive list of efficient assembly line organization plans, since production preparation was conducted within limited time using prototypes. The presented production preparation system can thus be called a 'new' preparation process, taking a different approach from a conventional one.

PLP follows the procedure explained above as well as the flow shown in Figure 5 to create 3DCGAs of assembly operations step by step based on the 3DCAD data, considering assembly line organizations as well.

Steps in the proposed procedure are summarized as follows:

STEP 1: Creating 3DCGAs for All the Possible Assembly Sequences Based on Products' Structures
STEP 2: Creating 3DCGAs for 'Operator-friendly' Operations, with Angles that are easy to operate
STEP 3: Creating 3DCG Animations Including the Use of Tools and Jigs
STEP 4: Considering Assembly Line Organization

As described earlier, Steps 1 through 3 pursue creating Assembly Steps which are error free and easy to operate. In addition to creating such Assembly Steps, PLP creates operations conducted by one operator in the form of animations, and thus enables evaluation of the contents of assembly operations. Step 4 pursues clarifying efficient production systems for operations, and considers production systems including assembly line system.

3. FLOW OF 3DCGA CREATION OF ASSEMBLY LINES WITH PLP

In this chapter, the 4-step procedure of PLP flow shown in Figure 5 is explained in more detail.

STEP 1: Creating 3DCGAs for All the Possible Assembly Sequences Based on Products' Structures

At Step 1, 3DCGAs for assembly plans for all possible assembly sequences are created using the products' 3DCAD data. Figure 6 shows the flow of 3DCGA creation with PLP system. The creation methods are to be described below following the flow in Figure 6.

PLP system flow can roughly be divided into two stages: the stage before creating the data with the proprietary developed language VFDL (Virtual Factory Description Language), and the stage after creating VFDL data. VFDL describes how computer manikins are virtually set in motion with the PLP system, and describes such motions with the sentence structures (Shinji and Akira, 2001). VFDL illustrates not only the position coordinates of computer manikins' hands, but also specific operations including "how objects are handled with computer manikins' hands and processed" together with hands' positions, as its characteristics. VFDL is characterized by its presentation methods' being easy to understand for everyone; operators can understand what they are expected to conduct in an operation and how they do it. VFDL also has a feature in that it includes all the necessary information in setting the computer manikins in motion. For example, the sentence structure used in Figure 4 includes the description on the positions of an operator's hands before and after conducting an operation (Note 1).

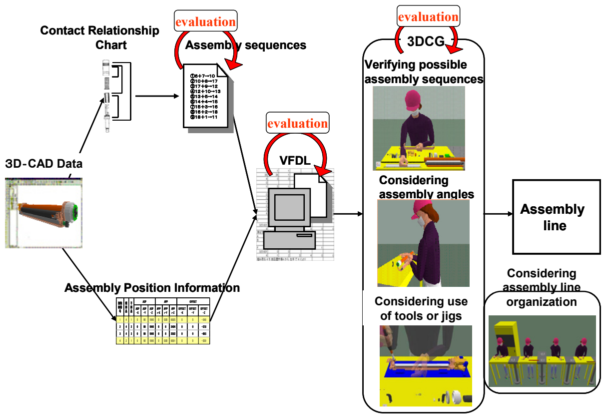

Figure 6. The flow of PLP system.

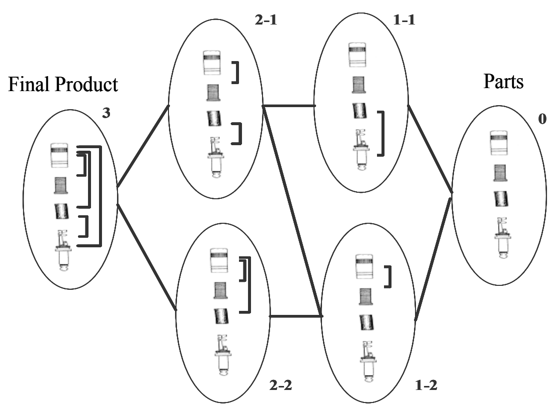

Figure 7. Creating assembly sequences using Contact Relation Chart.

At Stage 1, VFDLs are created from 3DCAD data, for possible assembly sequences. The number of total VFDLs created here is thus equivalent to that of all the possible assembly sequences. In order to do that, 2 kinds of data must be obtained from the 3DCAD data. The first is the "Contact Relationship Chart", as is shown in Figure 6. The chart illustrates how parts are attached to each other in a finished product, and shows how parts are arranged when they are disassembled axially, and using this chart, possible assembly sequences can be generated (Shinji SHINODA *et al.*, 2002). Figure 7 shows an example of Contact Relationship Chart of a finished product on the left, semi-finished products in the middle, and parts are shown on the right. By listing all the possible assembly patterns for each stage of assembly, it is possible to cover all the possible assembly sequences. The second is the "Assembly Position Information." The information specifies where the two out of the necessary parts are positioned and assembled for each assembly sequence (Shinji and Akira, 2002). As in Figure 8, the information shows the positions of parts in conducting assembly of parts specified in Contact Relationship Chart. The part to which another part is assembled is called "parent part", and the position of assembly is named ASP (ASsembly Position). The part to be assembled onto the parent part, on the other hand, is called "child part", and the location of positioning is named APP (APproach Position). When the two parts are assembled, the assembled status is called OFFSET. Using the information, assembly positions for each assembly sequence can be specified.

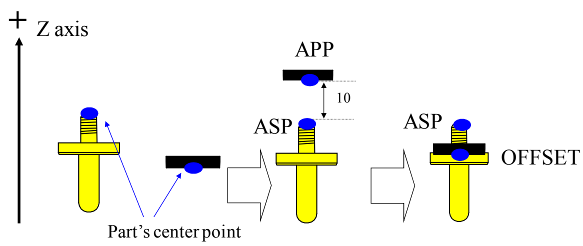

Figure 8. Example of assembly position chart.

At Stage 2, VFDLs are created from assembly sequences and Assembly Position Information. The information reflects the contents of Assembly Steps described earlier. Handling Steps are planned based on the information above, and VFDLs are to be completed (Shinji and Akira, 2001~2002). The created VFDL is converted into the language for operating DELMIA computer manikins on DELMIA software, and the 3DCGAs are displayed on the monitor (Note 2).

From above, it is possible to conclude that the motions of computer manikins are described in the created VFDLs, and that the essentials of PLP algorithms are to create such VFDLs. Also, evaluating the created VFDLs means assessing assembly operations in 3DCGAs quantitatively.

STEP 2: Creating 3DCGAs for 'Operator-friendly' Opera-tions, with Angles that are easy to operate

In manufacturing department, operators assemble parts to build a finished product by following the given assembly sequence, although the angles at which the operators can actually conduct operations are ergonomically limited. For example, it is easy to assemble parts from above or from the direction of the operators' dominant hands, while assembly from other directions is usually difficult, and the vision provided for operators is often limited, which could also cause difficulty in assembling parts. Taking above into consideration, PLP classifies parts assembly angles into 26 angles, first by categorizing angles matching X, Y and Z axes, and next horizontally, anteroposteriorly, vertically and by combinations of these three angles, as in Figure 9. The angles are classified into Category SI through III and the latter has higher level of difficulty in operating. Table 1 shows operations categorized from SI to III. In order to ensure the operations are 'error free', have less chance of errors being made in operation, and easy to operate, it is important that operators are able to "see" parts' assembly positions, and to operate with their dominant hands in conducting operations. Operations are categorized reflecting such operators' point of view. Operation angles can be simply calculated from the information on ASP and APP explained at Step 1.

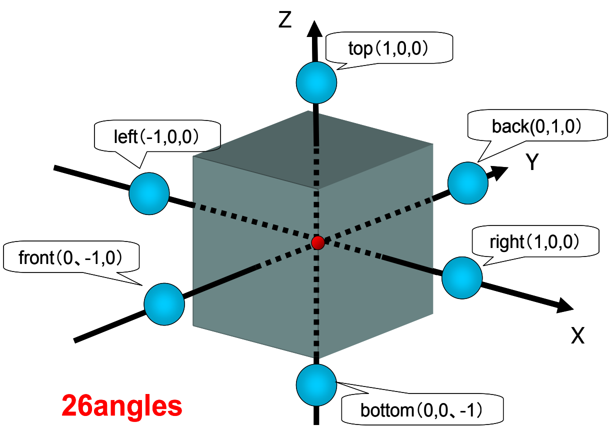

Figure 9. Assembly angles.

Table 1. Classification of assembly angle.

Category	Assembly angles are visually recognizable	Operators can assembly with dominant hands	Assembly positions are visually recognizable	angles
SI	○	○	○	T, FT, F
I	○	○		R, RT, RF, RFT
II	○			L, LT, LF, LFT
III				others

T = top, B = bottem, R = right, L = left, F = front, B = back
Where the operator is right-handed.

By categorizing operations as described above, PLP can also give answers to the questions below.

① What kinds of operation angles do the operations in question have, according to Category SI through III?

By clarifying the assembly angles, manufacturing department can predict how easy or difficult the operations would be in conducting. For manufacturing department, it is ideal to conduct operations from SI angles, which is the easiest angles from which to operate, and by planning operations with such angles, other information, such as how many times and how much the base part should be rotated to form easy or 'operatorfriendly' angles, may be clarified. It is also possible to give necessary feedback to the design department at this early stage to make alterations when the operations are found to require difficult operation angles.

② Utilizing PLP system, what kind of 3DCGAs for assembly operations can be created if operations are performed solely with Category SI operation angles?

Figure 10 shows examples of 3DCGAs used in considering operation angles with regard to the parts mentioned in chapter 1. The animation on the left shows the assembly plan which includes no base part movement. In this operation, the base part is set and fixed, and without rotating the base part, other parts are assembled onto the base part, which means parts can be assembled from any angles. The animation on the right, on the other hand, shows an 'extreme' assembly operation conducted solely with Category SI angles. As is shown in the figure, assembly positions or contact faces are easily recognizable in operation, and therefore easy to operate, although the operation includes base parts' vertical rotation. The animation in the center shows a revised operation proposed by the manufacturing department, and in this revised plan, the main operation angle is SI and base part's rotation is reduced to a minimum. Comparing and reviewing operations as stated above allow an objective evaluation of operations. For example, the original plan has 8 SI operation angles out of 37, and the 'extreme'

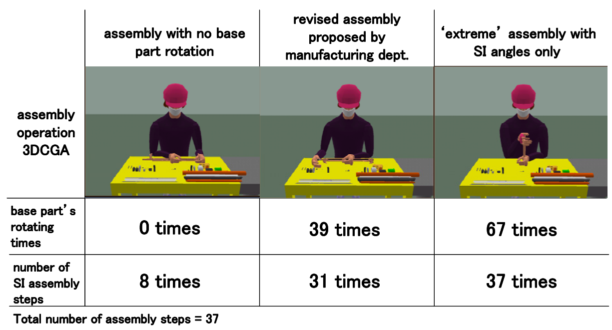

Figure 10. Considering assembly directions in assembly steps assembly directions.

plan involving only SI operation angles requires rotations of base parts 67 times. (Note 3) Operation angles can be altered simply by replacing assembly position information. Thus PLP has the feature of enabling evaluation and validation of such extreme plans with visual confirmation using created 3DCGAs, and allowing designers and operators to pursue ideal plans.

STEP 3: Creating 3DCG Animations Including the Use of Tools and Jigs

Although the operator-friendly assembly angles are clarified in Step 2, it does not always remove all the difficulties involved in an operation. In such cases, use of specific tools or jigs on the site is usual solution. For deciding what tools or jigs should be used, "Difficulty Factors" are identified and specified with PLP. "Difficulty Factors" clarify the difficulty levels of operations, in handling of parts or assembling, which can be detected and specified from the 3DCAD data. For example, in Figure 11, a sleeve-shaped part is to be attached to the base part. In such operations, an operator feels it difficult to assemble parts because point of gaze is not fixed, and there are two assembly points. In other words, the Difficulty factor here is that there are two or more assembly points involved in one step, and such factors are detectable in products' 3DCAD data. The details of such Difficulty Factors are presented in reference[11], and here in this paper, factors categorized as 17 Difficulty Factors are listed below.

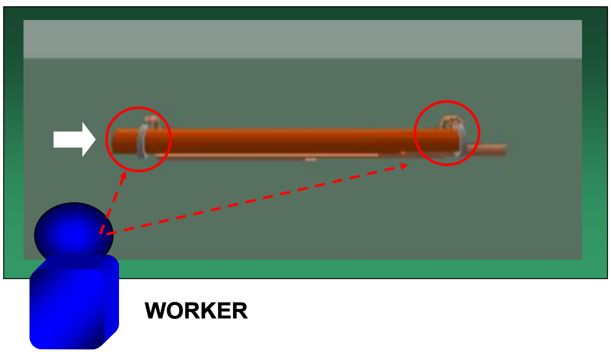

Figure 11. Explanation of difficulty factors.

17 Difficulty Factors are specified as follows:

(1) Difficulty Factors in "handling" objects
In terms of "handling" of objects, Difficulty Factors are classified into seven groups: size (large), size(small), thickness, weight, variability in shape, fragility, and unfixed contact

(2) Difficulty Factors in "positioning" objects
With regard to "positioning" of objects, Difficulty Factors are classified into seven categories: number of positioning points, symmetrical properties of parts, assembly space availability, visibility, contact point, side/direction restriction, and specified assembly

(3) Difficulty Factors in "assembling" objects
There are three factors: assembling force(weak force), assembling force(strong force), and assembling direction

Once the Difficulty Factors are clarified, tools or jigs are to be used to solve the problems in assembly operations. With PLP, a tool or jig to remove difficulty is selected for the Assembly Steps. Among all the possible assembly plans, the plan requiring the use of the smallest number of tools or jigs, and moreover, the smallest number of parts to be set on such tools or jigs will naturally be selected as the best plan. (Note 4) Detailed explanation of ways to select tools or jigs will not be repeated in this paper (Shinji Shinoda *et al.*, 2008), although an example of 3DCGAs which include the use of tools or jigs is given in Figure 5 partially.

STEP 4: Considering Assembly Line Organization

Operations that are easy for operators to perform are now specified from Steps 1 through 3. The next step considers assembly line organization based on the evaluations made for the operations. Products can be built with various systems including a cell production system performed by a single operator or a conveyer assembly system.

As for cell production system operations conducted by one operator, the operations are already clarified in Steps 1 through 3. Here assembly line organization plans are to be made by first dividing a one-person operation into several parts in various ways based on the number of processes in VFDLs and arranging them into an assembly line. Through Steps 1 through 3, tools or jigs to facilitate assemblies by providing operators easy-to-assemble angles or by promoting other operator-friendly factors have been clarified for all the possible

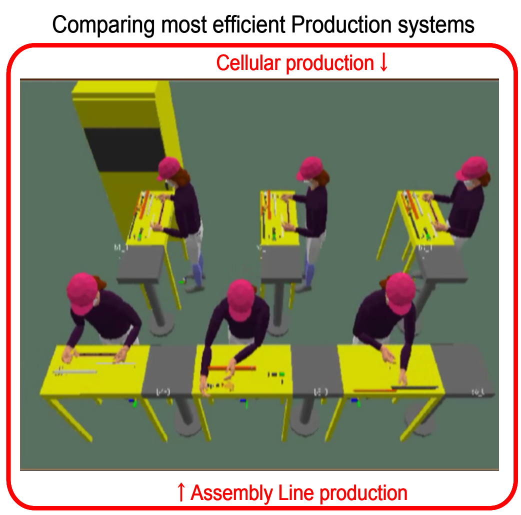

Figure 12. Comparing cellular production and assembly line production.

assembly operations corresponding each of the possible assembly sequences. By breaking down VFDLs of such one-person assembly operations according to the number of processes, and by putting them together to form an assembly line with the same number of processes, assembly line organization plans can be created. In the created assembly line organization plans, the orders or precedence relationship of processes must be carefully valued, and by honoring such a rule, various organization plans for assembly lines can be created. (Note 5) Figure 12 shows a rough comparison between the cell production system performed by 3 operators individually and the assembly conveyer system involving 3 operators. Taking a look at the number of parts allocated for each operator at their workshops, for example, with cell production system, each operator has more workload in terms of the number of parts they must assemble, but the operations are balanced in that an operator completes the tasks in their workshops. With assembly line system, each operator and process handles fewer parts, and as a result, the workload is reduced, although the tasks allocated for each operator may not be as balanced. This can be visually confirmed when the operation is put into motion, and the animation shows some operators have idle time while others keep operating. (Note 6)

4. CASE EXAMPLE

This chapter describes a case example in which PLP procedure shown in Figure 5 was applied for the production of a new product by Company X in 2006. For their new product M, PLP system was applied and assembly plans which are ‘error-free’, ‘easy-to-operate’ and efficient were sought at the design stage without using any prototypes. Utilizing PLP system, it was revealed that the selected operation was structured so parts are assembled onto one main part functioning as the base part. The operation angles in this selected operation were of Category SI and I, and the operation can be implemented with the use of one jig which has a simple rotating function, and the actual assembly line was formed according to the suggested plan. It took roughly 1 week to create this 3DCGA, and the assembly line was successfully organized and finalized without using any prototypes in the preparation process. The effectiveness of the process will be explained below.

For the purpose of comparing and clarifying the effectiveness of the PLP applied plan, a predecessor, product T, which has a similar structure as the product M is used as a counterpart here.

Figure 13 shows the number of steps involved in the assembly of products M and T. While M consists of 2 more parts compared with T, the number of steps involved in assembling a finished product for M is about 70% of the steps involved for T. This is because the plans with fewer steps were selected and adopted, considering all the possible assembly plans corresponding each of the possible assembly sequences. The adopted plan has less unnecessary movements, such as setting of parts on jigs, placing semi-finished products in a temporary storage, or other unnecessary handling. In other words, the number of Assembly Steps remains the same, while the number of Handling Steps is reduced in the selected plans.

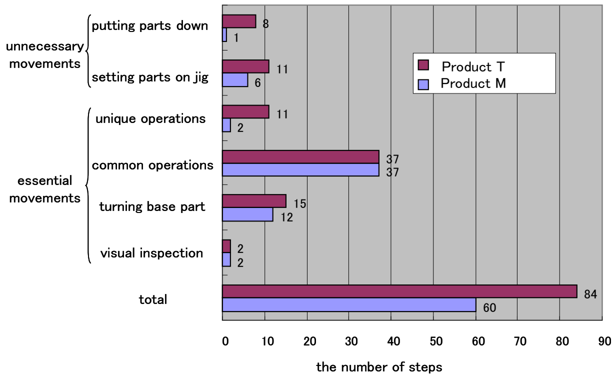

Figure 13. Comparing the number of steps for product T and product M.

Figure 14 illustrates differences between the preparation process man-hours of the two products. Preparation processes of production mainly include organizing operation processes, creating process specification forms and estimating man-hours, which constitute a large percentage of the estimated man-hours. The figure shows that the PLP applied plan has succeeded in reducing these man-hours drastically. Conventionally, ‘easy-to-operate’ and ‘efficient’ plans were proposed and selected using prototypes, and relying on production preparation engineers’ instinct or experience, within limited time. PLP offers production preparation as a whole process, including assembly line organization shown visually in 3DCGAs, and furthermore, contents of the operation are described in VFDL in detail. This has resulted in realizing work standardization or estimating work time without major trouble.

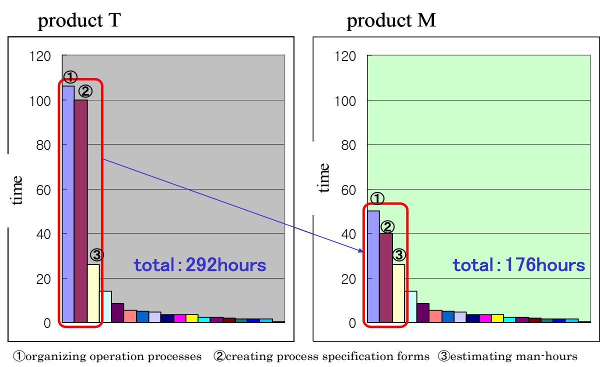

Figure 14. Comparing man-hours of preparation processes for product T and product M.

Figure 15 shows the man-hours for each stage of the preparation processes. Company X usually conducts trial production at the 4 stages of preparation process: initial trial production, modified trial production, mass-production trial, and production confirmation trial. Product T relies much on actual prototype, which results in increased man-hours at mass-production trial stage. Meanwhile, product M enables inspection and review on assembly plans mostly at modified trial production stage, which completes most of the preparation process. Moreover, efficient plans have already been discussed and proposed at this stage; mass-production trial planning is completed with much fewer man-hours as a result. From above, it can be concluded that it is important to create assembly line organization plans at an early stage due to the effectiveness of such preparation process.

The qualitative nature of PLP discussed in this study can be thus summarized as follows.

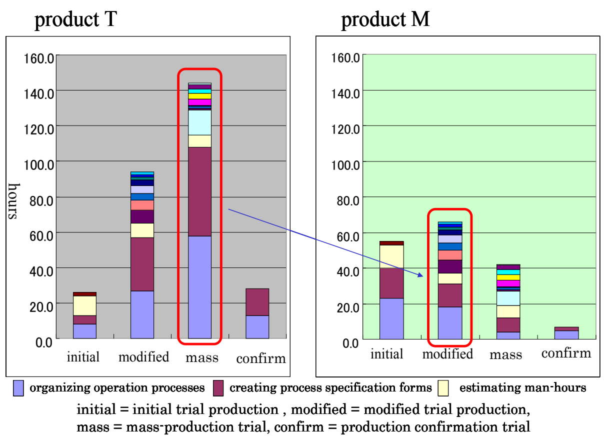

Figure 15. Comparing man-hours for each stage of the preparation process.

(1) Completing the Production Preparation Process Using PLP at the Design Stage

In general, design-related problems, such as difficulty in assembling products or unproductiveness of the plans have been identified rather later in a preparation process, after prototypes were built or after the assembly lines were set up. Problems regarding manufacturing, on the other hand, were related to the fact that completed assembly lines had to be changed or reestablished when design changes of the products arose. These problems used to make it even harder for the designing and manufacturing departments to work together. With PLP, 3DCGAs of assembly operations can be generated almost simultaneously once the 3DCAD data are created at the design department. Thus, utilizing PLP, designing and manufacturing departments can collaborate for more efficient production by altering design or by establishing process of production together, and can realize beneficial and economical production preparation.

(2) Effects of Visualization of Operations

Conventionally, although production preparation departments could design and set up assembly lines after examining prototypes, manufacturing departments could not visually check the products, except for taking a look at product drawings in some cases, until the products went on to mass production stage. With PLP, front-line operators can visually check what kinds of operations they are to perform using 3DCGAs in advance. Manufacturing departments can grasp the outlines of assembly lines at the design stage. For the manufacturing department, early stage involvement may help operators to get a general picture of the production line, understand what operations they are to perform, and to give feedback on manufacturing related problems.

(3) Simulations for Specifying Ideal Assembly Plans

PLP does not only aim at creating and launching an assembly line itself; it aims to create 'error-free', 'easy-to-operate' and efficient operations at an early stage. Utilizing computers, it is also possible to create an exhaustive list of alternative plans. If it becomes possible to discuss better plans at the design stage, it becomes even easier to assess and ensure the viability of the operations, compared with conventional preparation methods. Capturing the entire image of possible operation plans allows evaluating and appreciating the value of effective plans, making it easier to go on to the next task of organizing assembly lines with full confidence.

(4) Standardization and Digitalization of Rules Involved in an Assembly Operation

Assembly operations are performed according to a number of rules. Especially, with regards to Steps 2, 3 and 4, such rules differ depending on each company. For example, plans differ completely according to the company's capacity of whether or not they are able to devise and create tools or jigs. Many of such rules have been developed intuitionally or based on experience, so rules on assembly angles, levels of difficulty, tools or jigs or assembly line organization often vary according to each person and each company. By applying PLP methodology, such rules can be defined specifically, which may lead to standardization of production preparation process.

(5) Saving Man-hour for Data Entry

As mentioned earlier, with the conventional production preparation methods, it took a lot of time and efforts to create 3DCGAs of assembly operations, which made it especially difficult to verify assembly plans using 3DCGAs. Regarding assembly operations in particular, many businesses find it hard to carry out such time-consuming tasks. PLP can reduce such time and labor in utilizing 3DCGAs

5. CONCLUSION

This study proposed PLP system, methods and its application process consisting of 4 steps. Steps 1 through 3 of the 4 steps aim to create ‘operator-friendly’ assembly operations, after considering assembly sequences, assembly angles in each assembly sequence, and the use of tools or jigs with the operation angles, by focusing on the Assembly Steps in operations. Step 4 considers organizing assembly lines operated by multiple operators, and aims to increase the productivity of assembly operations. The features of the developed system presented in this study are that PLP can first create exhaustive list of possible assembly plans with 3DCGAs utilizing computers at the designing stage, and that it considers organizing assembly lines which are ‘easy-to-operate’ and efficient.

This study also dealt with a case in which PLP was applied for its production preparation process, and demonstrated how PLP can contribute to organizing effective assembly lines in a shorter period of time compared with the conventional methods, by creating and presenting ‘easy-to-operate’ and efficient assembly plans with the 3CGAs at the design stage.

The study on PLP is still in progress and further researches are to be made to put it in more practical use. The authors will continue working on and developing PLP to establish PLP as a ‘new’ practical method of manufacturing.

6. NOTES

1) From VFDL, a series of states and changes in an operation is created. The description method for VFDL is defined for each movement, and will not be explained in detail here. Figure 4 is shown as an example and it illustrates such states and changes in an operation partially.
2) Since VFDL contains all the necessary information to put the computer manikins in motion, it can be used on the software other than DELMIA’s once the conversion rule is clarified.
3) In operations, some semi-finished products need to be set onto or removed from tools or jigs before conducting the next operation step in an operation, which may require adjustments of placement angles when putting semi-finished products back to the original setting before rotation. Such adjustments are taken into consideration and added to the number of parts’ rotating times.
4) Both the number of tools or jigs and the number of times of setting parts on jigs or tools are specified for each operation, because in some assembly sequences, the same tools or jigs are used several times. Where the same jigs or tools are used several times, sequences requiring continued use of them is more efficient than those in which they are picked and placed several times.
5) Under current PLP system, each operation step is assessed based on the rough estimation of operation time, calculated for each operation step of VFDL. In general, such operation time was calculated from the estimated time for each element of operation conducted within an assembly sequence, after which assembly lines were organized. Since PLP organizes assembly lines based on operation steps or movements of VFDL, the time estimation is made more accurate with PLP.
6) As for the shop layout, in the present situation, designers decide and enter data as such before implementing operations. Automation of shop layout is a future area of investigation for the authors and the study is still in progress.

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