Journal of Manufacturing Systems 32 (2013) 412–416

Contents lists available at SciVerse ScienceDirect

Journal of Manufacturing Systems

journal homepage: www.elsevier.com/locate/jmansys

Technical Paper

An assembly decomposition model for subassembly planning considering imperfect inspection to reduce assembly defect rates

Jeonghan Ko[a,b,*], Ehsan Nazarian[c], Hui Wang[d], Jeffrey Abell[d]

[a] Department of Industrial Engineering, Ajou University, Woncheon-dong, Yeongtong-gu, Suwon-si, Gyeonggi-do 443-749, Republic of Korea
[b] Department of Industrial and Operations Engineering, The University of Michigan, Ann Arbor, MI 48109, USA
[c] Industrial and Management Systems Engineering, University of Nebraska-Lincoln, Lincoln, NE 68588, USA
[d] Manufacturing Systems Research Lab, General Motors Global Research & Development, Warren, MI 48090, USA

ARTICLE INFO

Article history:
Received 29 September 2012
Accepted 8 November 2012
Available online 10 January 2013

Keywords:
Assembly
Decomposition
Decision making
Design
Disassembly
Quality
Mixed-integer programming

ABSTRACT

The assembly decomposition is to divide the assembly to subassemblies that are to be joined in the final assembly processes. The assembly decomposition decision strongly affects the effectiveness of a product assembly in terms of quality, sequence and supplier selection. This paper presents an assembly-decomposition model to improve product quality. Mixed-integer programming is used to partition the liaison graph of a product assembly. The mixed-integer programming model takes into account the defect rates in components and assembly tasks. The defect rate of the final assembly product is to be minimized considering type II errors in subassembly inspection. A numerical example is presented to demonstrate the methodology, and this numerical study shows that assembly decomposition strongly affects the final assembly defect rate. The developed assembly decomposition method is expected to enhance the decision making in assembly planning.

1. Introduction

The assembly decomposition problem is to divide the product assembly to constituting subassemblies. These subassemblies are produced individually in the subassembly lines of a final assembler or by the suppliers for the final assembler. These subassemblies are joined together to make the final product in the main assembly line of the final assembler. Thus, the decision on the assembly decomposition, or subassembly decision, affects the whole assembly processes and supply chains as well as product characteristics.

In particular, the decision on the subassemblies affects the quality of the final assembly. Each subassembly has unique quality characteristics depending on the constituting components and their joining processes. In addition, because some subassemblies are inspected before the final assembly, different subassembly decisions will lead to inspection of different subassemblies. Thus, subassembly decisions will affect how the quality characteristics of components and joining processes propagate to the final assembly.

This study aims to establish a relationship between assembly decomposition and product quality. In spite of the extensive research on assembly design and quality [1–11], only limited number of research papers studied the effect of assembly decomposition on assembly quality. Moreover, little research directly considered the inspection error with the assembly decomposition. This paper presents an assembly decomposition model to minimize assembly defect rates considering imperfect inspection.

This paper presents an assembly decomposition methodology based on a graph-theoretic method. Graph partitioning methods have been widely used in assembly sequence planning [12–17]. This paper uses the liaison graph of a product assembly to represent the assembly and subassemblies. This study uses mixed-integer programming (MIP) to model the partition of the assembly graph. The MIP model considers the defect rates of components and assembly tasks. The model also considers type II errors in subassembly inspection. The objective function of the model is to minimize the defect rate of the final assembled product. A numerical example is presented to demonstrate the effect of assembly decomposition on the final assembly defect rate.

One of the purposes of this study is to establish a generic methodology that can be extended to more general cases of assembly decomposition and quality evaluation. Thus, this paper focuses on a straightforward assembly decomposition model that includes the fundamental characteristics of assembly decomposition. More

* Corresponding author at: Department of Industrial Engineering, Ajou University, Suwon-si, Gyeonggi-do 443-749, Republic of Korea. Tel.: +82 31 219 2335; fax: +82 31 219 1610.
E-mail addresses: jko@ajou.ac.kr (J. Ko), ehsan.nazarian@huskers.unl.edu (E. Nazarian), hui.wang@gm.com (H. Wang), jeffrey.abell@gm.com (J. Abell).

0278-6125/$ – see front matter
http://dx.doi.org/10.1016/j.jmsy.2012.11.001

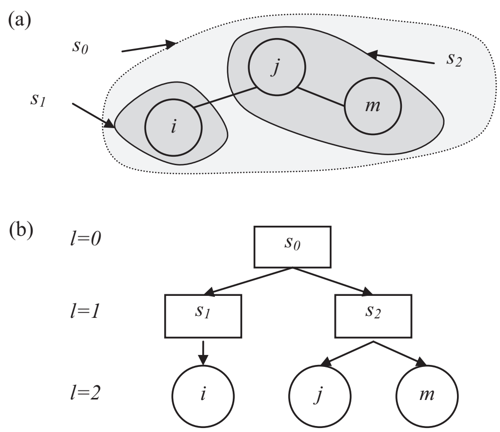

Fig. 1. Illustration of the layers and subassemblies in assembly decomposition. In (a), circles represent components, and straight lines between circles represent assembly tasks. Subassemblies are represented by shaded areas. In (b), rectangles represent subassemblies and circles at the bottom represent components. In (b), the highest layer ($l = 0$) indicates the final assembly. Tasks (i,j) is a cut edge in layer $l = 1$.

complex assembly relations and quality characteristics are planned to be handled in sequels of this study.

The paper is organized as follows. Section 2 defines the assembly decomposition problem. Section 3 defines assembly defect rates affected by subassembly inspection. Section 4 establishes mathematical models of assembly decomposition. Section 5 presents a numerical case study. Section 6 concludes the paper.

2. Definition of the assembly decomposition problem

The final assembly, subassemblies and subassembly structure are represented by graphs in this study. The assembly is represented as liaison graph $G = (V,E)$ in which vertices (V) correspond to the components in the assembly and edges (E) corresponds to the assembly tasks to join the components. For example, see Fig. 1. A subassembly is defined as a collection of components and all the assembly tasks between them. In the graph theoretic representation, a subassembly is equivalent to a connected subgraph that is separated by edge cuts from the other parts of the assembly graph. For instance, in Fig. 1, nodes j and m and edge (j,m) represent a subassembly s_2. The edges that are cut to generate subgraphs (subassemblies) represent assembly tasks to be performed for joining the subassemblies represented by the subgraphs.

This study assumes that the assembly decomposition is performed through three layers. The decomposition model with the three layers is general enough to be extended to more than three layers. In fact, due to the limited numbers in supplier tiers in industry and intentions to reduce assembly complexity in manufacturing, the decomposition layers are restricted to only some number of layers in practice.

The top layer in the assembly decomposition represents the final assembly, the mid-layer represents assembly decomposition to subassemblies, and the bottom layer represents the components of each subassembly including single-component subassemblies. In Fig. 1, the final assembly is denoted by s_0 and is decomposed into subassemblies s_1 and s_2 in $l = 1$.

In this study, subassembly decomposition is conducted by generating feasible partition sets of the graph representing the subassembly. In each decomposition, a set of subassemblies are generated by satisfying connectivity, precedence and other subassemblies constraints. The maximum number of subassemblies is given. Precedence relations of assembly tasks are also known

Table 1
Component defect rates.

Name	Defect rate	Name	Defect rate
C	0.005%	F	0.003%
H1	0.009%	W1	0.005%
H2	0.001%	W2	0.005%
H3	0.008%	W3	0.009%
E1	0.005%	W4	0.008%
E2	0.01%	W5	0.005%
E3	0.001%	W6	0.001%

in advance. Dimensional quality and degrees of freedom are not considered in this model. For these issues, see [1,2].

3. Subassembly defect rate and effect of imperfect subassembly inspection

Assume that the defect rates are known for the components and assembly tasks joining the components. Also assume that the component and assembly task defects are independent of each other. Although a more detailed analysis can be conducted using reliability modeling techniques such as fault tree analysis, without loss of generality this study assumes a simple case. Thus, the following equation represents a simple defect rate calculation for subassembly s, $\Delta(s) \approx \sum_i \delta_i + \sum_{(i,j)} \delta_{(i,j)}$ where δ_i and $\delta_{(i,j)}$ represent the defect rates of component i and assembly task (i,j), respectively. This subassembly defect rate is an approximated linear form ignoring higher order terms in the following equations.

$$\Delta(s) = Pr(s \text{ is defective})$$

$$= 1 - Pr\begin{pmatrix} \text{all components and their assembly} \\ \text{tasks in } s \text{ are non-defective} \end{pmatrix}$$

$$= 1 - \prod_i (1-\delta_i) \prod_{(i,j)} (1-\delta_{(i,j)})$$

The approximation will be good for small defect rates such as those in more than 3-sigma quality levels.

The defect rate of the final assembly depends on subassembly structure and inspection as well as the components and assembly tasks. Assume that an inspection is conducted between the times when a subassembly is constructed and it is joined for the final assembly. Since the inspection is not perfect, there is a possibility of accepting a nonconforming subassembly. This probability, known as the type II error probability and denoted by β, is incorporated in determining the defect rate of the final assembly. For example, in the subassembly structure shown in Fig. 1, $\Delta(s_0) \approx \delta_i + \delta_{(i,j)} + \beta(\delta_j + \delta_m + \delta_{(j,m)})$. The defect rate of assembly s_0 could be different than this if assembly task (i,j) was completed before (j,m) and component m was a single component subassembly. In general, the defect rate of the final assembly with the inspection of non-single component subassemblies is calculated as $\Delta(s_0) = \sum_s \{\beta(1-\gamma^s) \cdot \Delta(s) + \gamma^s \cdot \Delta(s)\}$, where γ^s is a binary variable indicating a single-component subassembly.

4. Mathematical model

This section describes the optimization model of the assembly decomposition incorporating the concepts shown in Sections 2 and 3. First, the mathematical symbols in the optimization model are explained in Section 4.1 below.