

January 01, 1999

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Recommended Citation

Gungor, Askiner and Gupta, Surendra M., "Disassembly line balancing" (1999). . Paper 40. <http://hdl.handle.net/2047/d10014044>

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Bibliographic Information

Gungor, A. and Gupta, S. M., "Disassembly Line Balancing", *Proceedings of the 1999 Annual Meeting of the Northeast Decision Sciences Institute*, Newport, Rhode Island, March 24-26, pp. 193-195, 1999.

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DISASSEMBLY LINE BALANCING

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ABSTRACT

In this paper, we discuss a new problem, the disassembly line balancing problem (DLBP), which can simply be defined as the optimum assignment of disassembly tasks to the disassembly workstations under the condition that the precedence relationships among the tasks are not violated. The objectives are to meet the demand and to utilize the disassembly line as efficiently as possible. We present a systematic approach to solve a simple DLBP. An example is also presented to illustrate the approach.

INTRODUCTION

Environmentally Conscious Manufacturing and Product Recovery (ECMPRO) has become an obligation to the environment and to the society itself, enforced primarily by governmental regulations and customer perspective on environmental issues [3]. Product recovery aims to minimize the amount of waste sent to landfills by recovering materials and parts from old or outdated products by means of recycling and remanufacturing (including reuse of parts and products). Recycling aims to recover the material content of retired products by performing the necessary disassembly, sorting, and chemical operations. On the other hand, remanufacturing preserves the product's (or the part's) identity and performs the required disassembly, sorting, refurbishing and assembly operations in order to bring the product to a desired level of quality. Disassembly has proven its role in material and product recovery by allowing selective separation of desired parts and materials [4].

The disassembly systems must be optimally designed and operated. In the disassembly literature, although the disassembly process planning has found a large following, only a handful of researchers have emphasized the shortcomings of the existing disassembly systems and suggested some improvements [5, 6, 8]. Current disassembly systems are generally manual and labor intensive. Therefore, designing and improving disassembly systems which optimize the use of resources (labor, money and time) are important and worth investigating.

In this paper, motivated by the fact that the disassembly systems need a lot of improvement, we address an unprecedented problem of disassembly line balancing (DLBP). Although, the traditional assembly line balancing problem (ALBP) has been around for a long time [9], no one has addressed the DLBP. Therefore, the primary objective of this paper is to draw attention to the research possibilities in this emerging area. We also present a systematic approach to solve a simple DLBP. An example is then presented to illustrate the approach.

THE DISASSEMBLY LINE BALANCING PROBLEM (DLBP)

The disassembly line is the part of a disassembly system where the returned products are taken apart for the purpose of recycling and remanufacturing. The line consists of several workstations and a material handling system, which allows the transportation of work-pieces from one station to another. The installation of a disassembly line is usually based on a long-term decision and requires a large capital investment. Therefore, it is important that such a system be designed and balanced so that it works as efficiently as possible. In order to find a balanced line, the DLBP must be solved.

At a first glance, the DLBP appears to be similar to the ALBP. However, due to unique characteristics of disassembly [1], the DLBP is a much more challenging problem. The DLBP, very simply, can be defined as follows: n disassembly tasks of a product with individual disassembly times must be assigned optimally to m disassembly workstations without violating the existing precedence relationships among disassembly tasks. Since this definition sounds very similar to the ALBP, one may ask the obvious question: "Why is it that the solution techniques developed for the ALBP cannot be used for the DLBP?"

The reasons lie in the physical and the operational differences between assembly and disassembly systems. Brennan et al. [1] compare the two systems, identify the unique characteristics of each system and point out the problems that are likely to arise in a disassembly system. For example, the disassembly system may face serious inventory problems because of the disparity between the demand for certain parts or subassemblies and their yield from disassembly. The flow processes of the two systems are also different. In an assembly environment, we deal with a "convergent" flow process (many parts converge to a single product), whereas in disassembly, the flow process is "divergent" (a single product is broken down into many subassemblies and parts). In the disassembly case, we also have to deal with a high degree of uncertainty in the structure and the quality of the returned products. In an assembly environment, where the parts undergo several quality checks before arriving at the assembly line, the level of uncertainty at the assembly stage is almost nonexistent. However, in disassembly, the condition of the products received is usually unknown; sometimes they are in good shape and relatively new, while at other times they are old, nonfunctioning items. The physical defects in the parts and/or joints may affect the precedence relationships among the parts and may lead to what we call the *Disappearing Work-pieces*

Phenomena (DWP) which can be described as follows: If a damaged part disables the removal of all other demanded parts in the work-piece because of certain precedence relationships, the work-piece may simply be taken off the disassembly line before it reaches the downstream stations. The work-piece “disappears” and the subsequent stations starve leading to a higher overall idle time, which is undesirable in a balanced line.

Another uncertainty issue is related to the quantity of the parts in the product. Due to upgrading (or downgrading) of the product during its use, the number of parts in the product may not match with its original configuration. The actual number of parts may be more (or less) than expected when the product is received. The demanded part(s) of the product may be absent or its quantity may be less than expected. To handle this situation, we might have to dynamically adjust the actual requirement for the number of products to be disassembled.

One other complication occurs when a work-piece splits into two or more work-pieces (subassemblies) as it moves on the disassembly line because of the removal of certain parts which hold the work-piece together. Each of these subassemblies acts as an individual work-piece on the disassembly line. We term this as the *Exploding Work-pieces Phenomena (EWP)*. The EWP complicates the flow control mechanism of the disassembly line.

There are various uncertainty factors associated with the reliability of the disassembly stations. Some parts of the product may cause pollution or nuisance due to the nature of their contents (e.g., oil, gas etc.) which increases the chance of breakdowns or downtimes of stations. Similarly, hazardous parts may require special handling, which can also influence the utilization of the stations. These uncertainty issues must be integrated into the DLBP solution process to achieve a balanced flow of the work-pieces on the disassembly line.

Various types of demand sources may also lead to complications in DLBP solution, viz., the demand source may accept the disassembled component ‘as is’ (Type 1 demand); the demand source may not accept parts with any type of defect (Type 2 demand); or the demand source may accept parts with defects depending on the seriousness of the defect (Type 3 demand). These demand considerations affect the number of products to be disassembled, and eventually the disassembly line balance.

OBJECTIVES AND CONSTRAINTS OF THE DLBP

The objectives of the DLBP are to utilize the resources of the disassembly line as efficiently as possible and meeting the demand. Efficient utilization of resources requires finding the minimum number of disassembly workstations required, optimally assigning the disassembly tasks to the stations, and improving the layout and material handling features of the disassembly line.

When achieving the above objectives, the precedence relationships among the tasks, must be satisfied. These

types of relationships also exist in the traditional ALBP. However, the precedence relationships in the ALBP are limited to simple AND types [2, 10]. These relationships are developed considering the physical and functional constraints, because the objective of the assembly process is to create a stable and functional end product. However, in the disassembly case, the parts are removed from the product without any concern of their interrelated functionality (only physical constraints are important). Therefore, we can relax the precedence relationships in the disassembly case by excluding the functionality constraints. This relaxation may require alternative representation of the precedence relationships. The relationships we consider in the disassembly case are AND, OR and complex AND/OR. In order to understand these terms, let p_i represent part i in a product to be disassembled. An *AND relationship* exists between p_1 and p_2 in relation to p_3 , if both p_1 and p_2 must be removed prior to p_3 . An *OR relationship* exists between p_1 and p_2 in relation to p_3 , if either p_1 or p_2 must be removed prior to p_3 . A *complex AND/OR relationship* exists between p_1 , p_2 , and p_3 , in relation to p_4 , if p_1 along with either p_2 or p_3 must be removed prior to p_4 .

A SIMPLE DLBP (DLBP-S)

In order to demonstrate a disassembly line balancing procedure, we study a simple DLBP (DLBP-S). The problem is defined as follows: A paced disassembly line is utilized to disassemble one type of product into its constituent parts and subassemblies. We assume that there is an infinite supply of products. The configuration of each product received is identical which means that the exact quantity of the parts in each product received is known. For simplicity, the disassembly times are assumed to be deterministic and known. Every part in the product has an associated demand, i.e., complete disassembly is targeted. The demand parameters are deterministic and known. The parts disassembled are accepted by the demand source in their current conditions (i.e., Type 1 demand).

A SYSTEMATIC APPROACH TO SOLVE THE DLBP-S

Due to the space limitation, we only present the basics of the approach without going into its mathematical details. The steps of the approach are as follows:

Step 1: Input R , c , and KB . Initialize the number of stations (or open a station), i.e., $k = 1$.

where:

- R disassembly precedence relationships matrix, representing the geometrically-based relationships among the parts (i.e., disassembly tasks), i.e., $R = \{r_{ij}; r_{ij} = 0, 1, \text{ or } d; \text{ and } i, j = 1 \text{ to } n\}$. (For a more detailed description of R , see reference [7]);
- c cycle time, that is the amount of time allocated to each station to complete its tasks. It is the ratio of the planning period length (L) to the number of products that need to be disassembled in order to meet the demand;

KB knowledge base of the product, which has the information related to the product; including demand levels (d_i), quantities (q_i), disassembly times (i.e., task times, t_i), disassembly movement directions (md_i), and the nature of the material content (e.g., hazardous, h_i) of the parts.

Step 2: If all tasks have been assigned to stations then go to Step 7.

Step 3: If $I_k < t_i, i = 1, \dots, n$, then open a new station, i.e., $k = k + 1$.

where:

I_k idle time of station k , i.e., $I_k = c - S_k$ where S_k is the station time of station k , i.e., $S_k = \sum t_j, j \in A_k$ where A_k is the set of tasks that are assigned to station k .

Step 4: Find CA_k .

where:

CA_k set of candidate tasks that can be assigned to station k . A task i is said to be *candidate* if and only if it satisfies the following three criteria: (1) Task i must not have already been assigned to any earlier station; (2) Task i must not have any predecessor or the tasks preceding it have been completed; and (3) $S_k + t_i \leq c$.

Step 5: Calculate the priority function value (F_i) for each task $i \in CA_k$.

where:

F_i priority function, which is used to select the best candidate task to be assigned to station k . F_i incorporates the following priority considerations: (1) Idle time of the stations; (2) Disassembly of highly demanded parts; (3) Parts that are easily accessible and precede many other parts (i.e., parts whose column in R are $\mathbf{0}$ and whose rows contain the most number of nonzero entities); (4) Parts with hazardous material content; and (5) Disassembly movement direction changes. Each of these considerations are given a priority value. Then, F_i of each candidate task is found by adding its priority values.

Step 6: Find the best candidate task j , which has the minimum F_j . Assign task j to station k , i.e., $A_k = A_k \cup j$. Go to Step 2.

Step 7: Print results; the number of stations, $M = k$, and the task assignment of the stations, $A_m, m = 1$ to M . STOP.

EXAMPLE

Consider the sample product shown in Figure 1a. The matrix R of the product is given in Figure 1b. Knowledge base (KB) associated with the product is presented in Table 1. Assume that part 4 contains hazardous material. Let a working day be defined by an 8-hour shift. Therefore, $L = 8 \times 60 = 480$ minutes. In order to fulfill the demand levels given in Table 1, the number of products (work-pieces) that need to be disassembled (given by the demand of parts 4

and 5 since their demand is the highest, assuming exactly one part of each type) is 20. Then, the cycle time, $c = 480/20 = 24$ minutes.

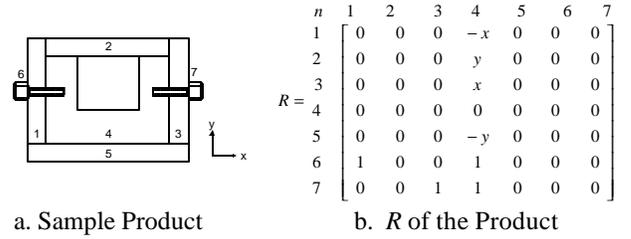


Figure 1: A sample product and its R

Table 1: The KB of the example product

Task i	t_i (min)	d_i (per day)	md_i^*
1	4	8	-x or y
2	10	10	y
3	10	12	x or y
4	15	20	x, -x, y, or -y
5	9	20	x, -x, or -y
6	8	14	-x
7	11	10	x

* Identified during the analysis of the product to generate R .

By applying the above approach, the number of stations, M , found for the sample problem is 3. The tasks have been assigned to stations as follows: $A_1 = \{7, 5\}$; $A_2 = \{6, 4\}$; and $A_3 = \{3, 2, 1\}$. The idle times of the stations have resulted as follows: $I_1 = 4$; $I_2 = 1$; and $I_3 = 0$ minutes. The overall idle time of the disassembly line is $I = 5$ minutes. If each task were assigned to one station, i.e., $M = 7$, the overall idle time would be 101 minutes. This clearly demonstrates the importance of utilizing a systematic approach for the disassembly line balancing problem.

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