IRis

Northeastern University

Department of Mechanical and Industrial Engineering

January 01, 2004

Disassembly sequencing problem: a case study of a cell phone

Evren Erbis
Northeastern University

Seamus M. McGovern
Northeastern University

Surendra M. Gupta
Northeastern University

Recommended Citation

Erbis, Evren; McGovern, Seamus M.; and Gupta, Surendra M., "Disassembly sequencing problem: a case study of a cell phone" (2004). . Paper 42. http://hdl.handle.net/2047/d10003319

This work is available open access, hosted by Northeastern University.

Laboratory for Responsible Manufacturing

Bibliographic Information

Gupta, S. M., Erbis, E. and McGovern, S. M., "Disassembly Sequencing Problem: A Case Study of a Cell Phone", ***Proceedings of the SPIE International Conference on Environmentally Conscious Manufacturing IV***, Philadelphia, Pennsylvania, pp. 43-52, October 26-27, 2004.

Copyright Information

Copyright 2004, Society of Photo-Optical Instrumentation Engineers.
This paper was published in Proceedings of SPIE (Volume 5583) and is made available as an electronic reprint with permission of SPIE. One print or electronic copy may be made for personal use only. Systematic or multiple reproduction, distribution to multiple locations via electronic or other means, duplication of any material in this paper for a fee or for commercial purposes, or modification of the content of the paper are prohibited.

Contact Information

Dr. Surendra M. Gupta, P.E.
Professor of Mechanical and Industrial Engineering and
Director of Laboratory for Responsible Manufacturing
334 SN, Department of MIE
Northeastern University
360 Huntington Avenue
Boston, MA 02115, U.S.A.

(617)-373-4846 ***Phone***
(617)-373-2921 ***Fax***
gupta@neu.edu ***e-mail address***

http://www.coe.neu.edu/~smgupta/ ***Home Page***

Disassembly Sequencing Problem: A Case Study of a Cell Phone

Surendra M. Gupta*, Evren Erbis and Seamus M. McGovern
Laboratory for Responsible Manufacturing
334 SN, Department of MIE
Northeastern University
360 Huntington Avenue
Boston, MA, 02115 USA

ABSTRACT

Selection of an optimal disassembly sequence is essential for the efficient processing of a product at the end of its life. Disassembly sequences are listings of disassembly actions (such as the separation of an assembly into two or more subassemblies, or removing one or more connections between components). Disassembly takes place in remanufacturing, recycling, and disposal with a disassembly line being the best choice for automation. In this paper, the disassembly sequencing problem is solved for a cell phone case on a disassembly line, seeking a sequence which is feasible, minimizes the number of workstations (and hence idle times), provides for early removal of high demand/value parts, provides the removal of parts that lead to the access of greatest number of still-installed parts, and early removal of hazardous parts as well as for the grouping of parts for removal having identical part removal directions. Since finding the optimal sequence is computationally intensive due to factorial growth, a heuristic method is used taking into account various disassembly-specific matters. Using the experimentally determined precedence relationships and task times of a real-world cell phone, a MATLAB program is designed and a sequencing solution is generated. Finally, Design for Disassembly (DFD) improvements are recommended with respect to environmentally conscious manufacturing.

Keywords: Disassembly sequencing, disassembly line, reverse logistics, data set, design for disassembly, multiple criteria optimization, product recovery, environmentally conscious manufacturing.

1. INTRODUCTION

Following the industrial revolution, manufacturing started to influence everyday life with new products rapidly entering the marketplace. Since then, products have been routinely disposed of in landfills at the end of their lives. Until recently, there was no major concern over landfill growth or hazardous materials entering the environment, nor was there a realization of the value of used parts, components and materials. In the last decade, however, environmentally conscious manufacturing (ECM) and product recovery have became an obligation for many companies due to new government regulations and consumer interest [5]. Consequently, companies have grown increasingly interested in how to efficiently disassemble the products they manufacture. They have invested time, money and engineering expertise in determining how customers return end of life (EOL) products (reverse logistics) and how to make the product recovery process profitable, or at least be conducted at minimum cost.

Within these researches, numerous ways for efficiently performing disassembly processes have been proposed. The most promising of these recommendations is the creation of disassembly lines, similar in concept to assembly lines, but with several significant differences. Small products, especially those with hazardous and/or valuable parts, are especially suited to the disassembly line due to their ease of collection, portability, and typically larger production numbers when compared to large products which are often more convenient to disassemble in place rather than relocating them on a line. Larger products are also prone to repair and maintenance as well as modification, making successful and consistently efficient disassembly on a line more of a challenge.

In the past decade, the use of cellular phones has grown significantly. Due to rapid changes in usage, technology (e.g., analog to digital), and features (e.g., color, web access), dozens of new models regularly enter the market. Consumers have responded by willingly replacing their old phones with newer technologies, often with their current phone not yet at the end of its useful life and still fully functional. These unwanted cell phones eventually end up in landfills and typically

* gupta@neu.edu; phone 1 617 373-4846; fax 1 617 373-2921; URL http://www.coe.neu.edu/~smgupta/

Environmentally Conscious Manufacturing IV, edited by Surendra M. Gupta,
Proceedings of SPIE Vol. 5583 (SPIE, Bellingham, WA, 2004)
0277-786X/04/$15 · doi: 10.1117/12.577196

contain numerous hazardous parts including: mercury, cadmium, lead, gallium arsenide and beryllium. These materials, if improperly disposed, can pose a significant threat to the environment.

While data sets have been developed to test disassembly algorithms [6] [13], no thorough, realistic, actual application examples have yet been established. In this paper, the Samsung SCH-3500 cell phone is examined in order to provide a practical example for disassembly sequencing and disassembly line balancing problems. A MATLAB application of a previously developed algorithm is then presented along with its calculated solutions using the SCH-3500 data.

2. LITERATURE REVIEW

Brennan, *et al*. provide an overview of disassembly [1] while Gungor and Gupta present a survey of environmentally conscious manufacturing and product recovery [5]. Disassembly optimization using goal programming and considering financial and environmental factors are demonstrated in [7] and [18]. Veerakamolmal and Gupta analyze design efficiency for the disassembly of electronic products by building up an index for measuring and comparing efficiency [17]. Moore *et al*. use Petri nets with products having complex AND/OR precedence relationships [9]. Gungor and Gupta study disassembly in processes that included possible task failures [2] and demonstrate how various factors, including component value and hazardous parts content, could be accommodated to balance a paced disassembly line [3]. Lambert provides a timely and thorough survey of disassembly sequencing [8]. Metaheuristic techniques are applied to the disassembly line balancing problem in [11], [14], [15], and [16] while deterministic algorithms are developed in [10] and [12].

3. NOTATION

The following notation is used in the remainder of the paper:

$\lceil x \rceil$	Largest integer $\leq x$
a	Chosen task for assignment
c	Cycle time
$dir.code$	Direction code
$(dir.code)$`	New direction code
$f(Hd)$	Weighting function for $Hd(i)$
$f(Id)$	Weighting function for Id
$f(Md)$	Weighting function for $Md(i, j)$
$f(Rv)$	Weighting function for $Rv(i)$
$f(Sr)$	Weighting function for $S(k)$
Fi	Summary weighting function
$Hd(i)$	Hazardous index for task i
Id	Idle time
k	Workstation index
N	Number of parts in a given product
M	Number of workstations
M_{i-}	i^{th} row of precedence matrix
M_{-j}	j^{th} column of precedence matrix
$Md(i, j)$	Index of direction change between tasks i and j
$Rv(i)$	Resale value of part removed in task i
$S(k)$	Time remaining in workstation k
$Sr(i)$	Number of successor tasks to task i
$t(i)$	Time required to perform task i

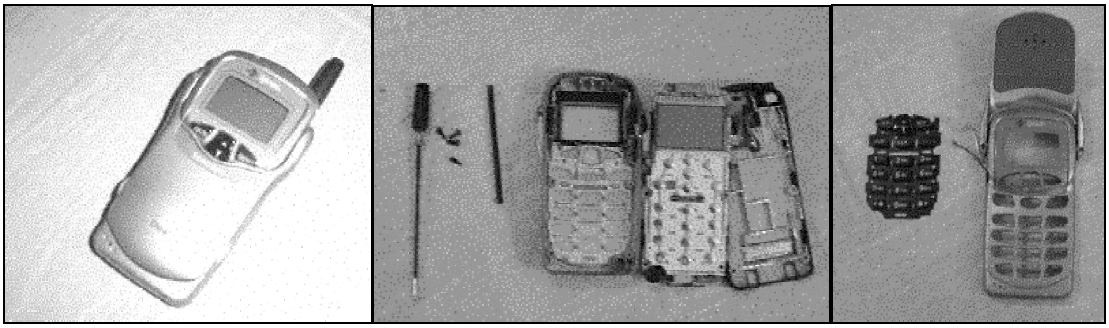
4. THE MODEL DESCRIPTION

The 2001 model year Samsung SCH-3500 is selected for analysis. Collected data on the SCH-3500 is listed in table 1, including part count, resale value and weight in grams (resale value is an estimate based on part value and/or recycling value).

Table 1. SCH-3500 cell phone parts and their properties

Part ID	Part Name	Part Count ({Qj})	Resale Value (Rvj)	Weight (Dwj) (gr)
P1	*Antenna*	1	4	3.50
P2	*Battery*	1	7	54.82
P3	*Antenna Guide Path*	1	1	0.16
P4	*Bolt (Type1)*	2	1	0.15
P5	*Bolt (Type2)*	4	1	0.20
P6	*Clip*	1	2	5.30
P7	*Rubber Seal*	1	1	2.95
P8	*Speaker*	1	4	2.10
P9	*White Cable*	1	1	0.10
P10	*Red/Blue Cable*	1	1	0.15
P11	*Orange Cable*	1	1	0.20
P12	*Metal Top*	1	1	0.22
P13	*Front Cover*	1	2	17.46
P14	*Back Cover*	1	2	16.80
P15	*Circuit Board*	1	8	24.47
P16	*Plastic Screen*	1	1	1.10
P17	*Keyboard*	1	4	4.03
P18	*LCD*	1	6	3.34
P19	*Sub-keyboard*	1	7	9.14
P20	*Internal IC Board*	1	1	5.01
P21	*Microphone*	1	4	0.05
Total		**25**		**151.25**

Figs. 1a to 1c show the complete SCH-3500 as well as the phone in various stages of disassembly. In Fig. 1b the antenna and antenna guide path have been removed along with the four securing bolts. In Fig. 1c the keyboard and the front cover of the cell phone are separated prior to removing the connecting clip and rubber seal.



Figs. 1a, 1b and 1c. Cell phone and several stages of disassembly.

Table 2 lists the tasks for disassembly of SCH-3500. These tasks and their times were determined experimentally. It is recognized that the time required for each task decreases as it is learned. The tasks listed in table 2 were repeated until a steady-state of part removal performance was attained. Five different directions (+x, +y, -y, +z, -z) were noted, while *Sr* is a listing of the number of possible successor tasks.

Table 2. SCH-3500 cell phone disassembly tasks

Task number	*Task name*	*Time*	*Direction*	*dir.code*	*Sr*
1	remove **Antenna**	3	(+y)	4	15
2	remove **Battery**	2	(-y)	5	18
3	discard **Antenna Guide Path**	3	(-z)	7	14
4	remove **Bolt (Type1) A**	10	(-z)	7	3
5	remove **Bolt (Type1) B**	10	(-z)	7	3
6	remove **Bolt (Type2) 1**	15	(-z)	7	13
7	remove **Bolt (Type2) 2**	15	(-z)	7	13
8	remove **Bolt (Type2) 3**	15	(-z)	7	13
9	remove **Bolt (Type2) 4**	15	(-z)	7	13
10	remove **Clip**	2	(+z)	6	2
11	remove **Rubber Seal**	2	(+z)	6	1
12	remove **Speaker**	2	(+z)	6	0
13	disconnect **White Cable**	2	(-z)	7	8
14	disconnect **Red/Blue Cable**	2	(+y)	4	8
15	disconnect **Orange Cable**	2	(+x)	2	3
16	remove **Metal Top**	2	(+y)	4	3
17	remove **Front Cover**	2	(+z)	6	6
18	remove **Back Cover**	3	(-z)	7	2
19	remove **Circuit Board**	18	(-z)	7	1
20	remove **Plastic Screen**	5	(+z)	6	0
21	remove **Keyboard**	1	(+z)	6	4
22	discard **LCD**	5	(+z)	6	2
23	remove **Sub-keyboard**	15	(+z)	6	1
24	remove **Internal IC Board**	2	(+z)	6	0
25	remove **Microphone**	2	(+z)	6	0
TOTAL		**155**			

During disassembly, the following precedence relationships were observed:

1 → ϕ
2 → ϕ
3 → 1 & 2
4 → ϕ
5 → ϕ
6 → 2
7 → 2
8 → 2
9 → 3
10 → 4 & 5
11 → 10
12 → 11
13 → 6 & 7 & 8 & 9
14 → 6 & 7 & 8 & 9
15 → 6 & 7 & 8 & 9
16 → 6 & 7 & 8 & 9
17 → 13 & 14
18 → 15
19 → 13 & 14 & 16 & 18
20 → 17
21 → 17
22 → 21
23 → 16 & 22
24 → 19 & 23
25 → 21

Problem assumptions include the following:

- A single product type is to be disassembled on a disassembly line,
- The supply of the end-of-life product is infinite,
- The exact quantity of each part available in the product is known and constant,
- A disassembly task cannot be divided between two workstations,
- Each part has an assumed associated resale value which includes its market value and recycled material value,
- Disassembly tasks are to be assigned to a sequence of workstations without violating precedence relationships among the tasks, and
- Complete disassembly is performed on the product.

5. MATHEMATICAL FORMULATION

5.1. Workstation and cycle time calculation

The cycle time (c) is given by

$$c = \frac{duration_of_planning_period}{\#of_products_to_be_disassembled} = \frac{L}{dv_{\max}} \tag{1}$$

and is constrained by

$$t_i \le c, \text{ for } i = 1, \ldots, N \tag{2}$$

Therefore, c can be defined as

$$c = t_{\max} \tag{3}$$

where

$$t_{\max} = \max(t_1, t_2, \ldots t_N) \tag{4}$$

For the cell phone example, we find $c = t_{\max} = 18s$.

A second objective is to minimize the number of stations for the purpose of reducing cost. Here, we have:

$$M_{\min} = \left\lceil \frac{T}{c} \right\rceil = \left\lceil \frac{T}{t_{\max}} \right\rceil \tag{5}$$

Therefore, $M_{\min} = \left\lceil \frac{155}{18} \right\rceil = 9$ workstations. Also, the maximum number of workstations is equal to the maximum number of tasks, giving:

$$M_{\max} = N \tag{6}$$

For this problem, $M_{\max} = 25$, therefore:

$$M_{\min} \le M \le M_{\max} \tag{7}$$

or

$$9 \le M \le 25 \tag{8}$$

5.2. Multi-criteria priority weighting function generation

It is desired to remove the highly demanded parts and the hazardous parts as early as possible. By doing this, valuable or desirable parts are less likely to be damaged and hazardous parts are less likely to cause damage and can be removed safely. In addition, these priorities provide the opportunity to terminate the disassembly early. It is also desired to remove parts with similar part removal directions together in the sequence for the sake of efficiency, and to remove parts based on the amount of access they provide to the remaining parts in the product in order to maximize the options available to any search algorithm or heuristic.

Based on this, a multi-criteria weighting function is developed to heuristically generate a disassembly sequence. This function is then used by a Next-Fit algorithm to assign the sequence of parts to workstations on the disassembly line. Next-Fit is used instead of First-Fit-Decreasing or some other rule due to the existence of precedence constraints which must be enforced.

In this study, the highest priority goal is to minimize the number of workstations; this assures a minimum overall idle time. Additional goals, presented in order of priority, include removal of high value parts, parts with a larger number of

successor tasks, parts containing hazardous elements, and parts that are removed in the same direction as the previously removed part. The following functions have been developed based on [3].

$f(Id_{i,k})$ describes the weight calculated due to the idle times at the workstations where:

$$Id_{i,k} = c - (S(k) + t(i)),\ i \in candidateTasks \tag{9}$$

with the weight increasing with the increase in idle time.

$f(Rv_i)$ describes the weight attributed to the resale value of the parts with this weight decreasing with positional assignments of high value part early in the disassembly sequence.

$f(Sr_i)$ describes the weight due to ease of accessibility to other parts due to precedence constraints with the weight decreasing with increase in the number of successors.

$f(Hd_i)$ describes the weight generated by parts with hazardous content. It consists of a binary variable where

$$Hd_i = \begin{cases} 1, if.hazardous \\ 0, otherwise \end{cases} \quad \text{for } i = 1,\ldots,N \tag{10}$$

with the weight decreasing with positional improvement in hazardous part placement in the disassembly sequence.

$f(Md_i)$ describes the weight given to minimizing the disassembly direction changes with the weight increasing with increase in Md .

Summing up these five functions results in the following weighted function:

$$F_i = f(Id_{i,k}) + f(Rv_i) + f(Sr_i) + f(Hd_i) + f(Md_i) \tag{11}$$

After calculating all of the weighted values for each subsequent, feasible task, the task generating the smallest *F* is selected for removal. If there are multiple, minimum *F*s, each of the possible tasks are then evaluated for individual weight components in the following order: minimum idle time, earliest high value part removal, maximum number of successors, earliest hazardous content part removal, and minimum direction change.

5.3. The precedence matrix

A modified precedence matrix, *M*, is used to summarize the precedence relationships. In this study, the precedence matrix contains the AND, OR, and AND/OR relationships as well as the directions of the OR tasks. Table 3 displays all of the possible direction codes; 0 and 1 are skipped since they perform other roles in the matrix.

Table 3. Disassembly task direction codes

Direction	Dir.code
(+x)	2
(-x)	3
(+y)	4
(-y)	5
(+z)	6
(-z)	7

To simplify programming in MATLAB, the disassembly precedence matrix is modified as follows; precedence relationships are generated based on task *i*, where

- *i* is not related to task *j*: set m_{ij} =0
- *i* is AND precedent to task *j*: set m_{ij} = 1
- *i* is OR precedent to task *j*: set m_{ij} = $dir.code_i$
- *i* is AND-within-OR precedent to task *j*: set m_{ij} = ($dir.code$)`

- *i* is OR-within-AND precedent to task *j*: set $m_{ij} = (dir.code)$`

Examples are shown below.

In Fig. 2, tasks *i* and *k* are both AND precedents of task *j*. Therefore both m_{ij} and m_{kj} are set equal to 1 in matrix *M*. The other elements in M_{-j} would be set equal to 0.

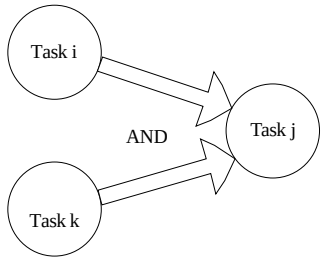


Fig. 2. AND precedence.

Fig. 3 shows an example of an OR relationship. Task *i* OR *k* should be completed before assigning task *j*. Therefore, m_{ij} and m_{kj} are assigned the direction codes of *i* and *k* respectively (it is assumed that tasks *i* and *k* always have different directions as a result of being in an OR relationship with the same task [4]).

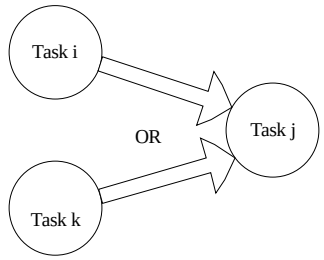


Fig. 3. OR precedence.

In Fig. 4, before assigning task *j* to a workstation, tasks *i* AND *k*, OR tasks *m* AND *n* must be assigned first; this is an example of AND-within-OR precedence. For programming purposes, if tasks *i* and *k* are removed in different directions, the one that differs from other OR relationship is assigned to m_{ij} and to m_{kj} ; if both directions are the same, the value 8 is assigned.

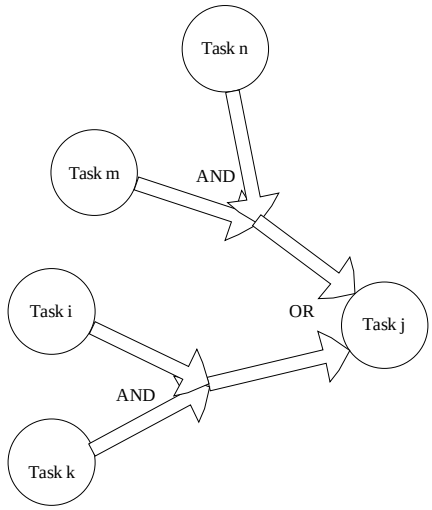


Fig. 4. AND-within-OR precedence.

An example of OR-within-AND is shown in Fig. 5. Differing direction codes are used for the OR branches while, instead of the actual direction code, m_{mj} =1 and m_{nj} =1 is used to represent the AND branches.

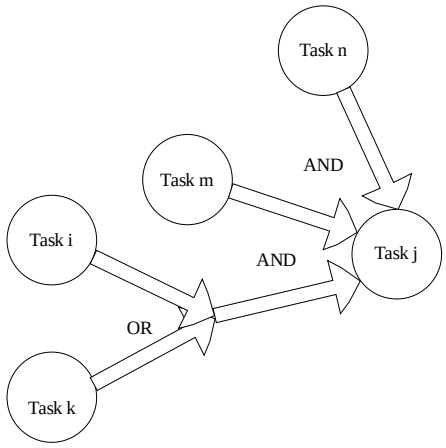


Fig. 5. OR-within-AND precedence.

6.SOFTWARE DEVELOPMENT

A MATLAB program was developed for assigning the cell phone disassembly tasks to a minimum number of workstations while preserving precedence and addressing the function weights. MATLAB is a high-level technical computing language and interactive environment for algorithm development, data visualization, data analysis, and numerical computation.

The program requires the following inputs:

- Precedence relationships,
- Task times,
- Resale value,
- Hazardous binary value,
- Direction of disassembly,
- Number of predecessors to each task,

and provides these outputs:

- The individual tasks assigned to each workstation and their sequence,
- Number of workstations,
- Idle time at each workstation.

7. NUMERICAL RESULTS

Running the MATLAB program with the previously described inputs provides the solution listed in table 4.

Table 4. Disassembly sequence results

Work Station	Tasks Assigned	Work Station Time	Idle Time
1	{2,6}	17	1
2	{7,1}	18	0
3	{8,3}	18	0
4	{9,13}	17	1
5	{4,14,17,21,25}	17	1
6	{5,22,10}	17	1
7	{20,15,18,16,11,12}	16	2
8	{19}	18	0
9	{23,24}	17	1
	TOTAL	**155**	**7**

As seen from the assignment, in the first workstation, task 2 is completed first. Completing task 2 is necessary to free task 6, since it is the sole predecessor to task 6. After assigning two tasks to workstation 1, the idle time remaining is 1 second and there are no available tasks with a task time less than or equal to 1 so the algorithm invokes the Next-Fit rule and creates a new workstation and continues its search.

The final result provides a total idle time of 7 seconds. The maximum idle time at any one workstation is only 2 seconds (found only once, in the 7th workstation). Most of the stations (5 of the 9) have idle times of 1 second and three have idle times of zero. Therefore, one can conclude that this disassembly sequence appears to be optimally balanced (minimum workstations and similar idle times across workstations) as well. Total time for the process (workstation times plus idle times) is 162 seconds with 4.32% of that as idle time (note that tool change time is not considered in this study). The algorithm obtained the optimally calculated number of workstations, 9, as given by equation (8).

Though not seen with the SCH-3500 cell phone data, an important weakness of the developed algorithm is its inability to consistently balance the workstations, specifically in the last workstation. This can be attributed to the use of the Next-Fit rule (developed for the bin-packing problem) in assigning tasks to workstations, but can be addressed by trial and error through increasing or decreasing c in increments of 1.

While this heuristic approach to the disassembly sequencing problem cannot assure an optimum solution, it is able to rapidly generate near-optimum solutions and its result is much faster than searching the N! permutations required to ensure the optimum sequence.

The SCH-3500 cell phone has already been designed and manufactured for the market. However, if new production versions of the SCH-3500 are made, one could make some improvements in the design for ease of disassembly. One recommended improvement would be a redesign of the antenna guide path. The current antenna guide path design does not allow access to one of the bolts required for disassembly. Thus, until disassembling the antenna and its guide path, one cannot obtain access to any other internal components, limiting options and mandating the early removal of this component.

8. CONCLUSIONS

In this paper, a disassembly case study of an existing, contemporary cell phone was described. A weighted algorithm was developed and programmed in MATLAB that provided a feasible part removal sequence while attempting to find the sequence having the minimum number of workstations (minimum idle time) as well as providing consideration for early removal of high demand/value parts, whose removal provides access to the greatest number of still-installed parts, hazardous parts, and removing parts with identical part removal directions adjacent to each other in the sequence. Although a sub-optimum heuristic, this method quickly generated a feasible solution to this complex, real-world problem example, while the experimentally determined data provides a new evaluation tool for future disassembly algorithm development.

REFERENCES

[1] L. Brennan, S. M. Gupta, and K. N. Taleb, "Operations Planning Issues In An Assembly/Disassembly Environment," *International Journal of Operations and Production Planning*, Vol 14, No. 9, pp. 57-67, 1994.

[2] A. Gungor and S. M. Gupta, "A Solution Approach To The Disassembly Line Problem In The Presence Of Task Failures," *International Journal of Production Research*, Vol 39, No. 7, pp. 1427-1467, 2001.

[3] A. Gungor, and S. M. Gupta, "Disassembly Line In Product Recovery," *International Journal of Production Research*, Vol 40, No. 11, pp. 2569-2589, 2002.

[4] A. Gungor and S. M. Gupta, "Disassembly Sequence Plan Generation Using A Branch-And-Bound Algorithm," *International Journal of Production Research*, Vol 39, pp. 481-509, 2001.

[5] A. Gungor and S. M. Gupta, "Issues In Environmentally Conscious Manufacturing And Product Recovery: A Survey," *Computers and Industrial Engineering*, Vol 36, No. 4, pp. 811-853, 1999.

[6] S. M. Gupta and S. M. McGovern, "Multi-Objective Optimization In Disassembly Sequencing Problems," *Proceedings of the 2nd World Conference on Production & Operations Management and the 15th Annual Production & Operations Management Conference*, April 30-May 3, Cancun, Mexico, CD-ROM, 2004.

[7] E. Kongar and S. M. Gupta, "A Multi-Criteria Decision Making Approach For Disassembly-To-Order Systems," *Journal of Electronics Manufacturing*, Vol 11, No. 2, pp. 171-183, 2002.
[8] A. J. D. Lambert, "Disassembly Sequencing: A Survey," *International Journal of Production Research*, Vol 41, No. 16, pp. 3721-3759, 2003.
[9] K. E. Moore, A. Gungor, and S. M. Gupta, "Petri Net Approach To Disassembly Process Planning For Products With Complex AND/OR Precedence Relationships," *European Journal of Operational Research*, Vol 135, pp. 428-449, 2001.
[10] S. M. McGovern and S. M. Gupta, "2-Opt Heuristic For The Disassembly Line Balancing Problem," *Proceedings of the SPIE International Conference on Environmentally Conscious Manufacturing III*, October 27-31, Providence, Rhode Island, pp. 71-84, 2003.
[11] S. M. McGovern and S.M. Gupta, "Demanufacturing Strategy Based Upon Metaheuristics," *Proceedings of the 2004 Industrial Engineering Research Conference*, May 15-19, Houston, Texas, CD-ROM, 2004.
[12] S. M. McGovern and S. M. Gupta, "Greedy Algorithm For Disassembly Line Scheduling," *Proceedings of the 2003 IEEE International Conference on Systems, Man, and Cybernetics*, October 5-8, Washington, DC, pp. 1737-1744, 2003.
[13] S. M. McGovern and S. M. Gupta, "Metaheuristic Technique For The Disassembly Line Balancing Problem," *Proceedings of the 2004 Northeast Decision Sciences Institute Conference*, March 24-26, Atlantic City, New Jersey, pp. 223-225, 2004.
[14] S. M. McGovern and S. M. Gupta, "Multi-Criteria Ant System And Genetic Algorithm For End-Of-Life Decision Making," *Proceedings of the 35th Annual Meeting of the Decision Sciences Institute*, November 20-23, Boston, Massachusetts, 2004.
[15] S. M. McGovern, S. M. Gupta, and S. V. Kamarthi, "Solving Disassembly Sequence Planning Problems Using Combinatorial Optimization," *Proceedings of the 2003 Annual Meeting of the Northeast Decision Sciences Institute*, March 27-29, Providence, Rhode Island, pp. 178-180, 2003.
[16] S. M. McGovern, S. M. Gupta, and K. Nakashima, "Multi-Criteria Optimization For Non-Linear End Of Lifecycle Models," *Proceedings of the Sixth Conference on EcoBalance*, October 25-27, Tsukuba, Japan, 2004.
[17] P. Veerakamolmal and S. M. Gupta, "Analysis Of Design Efficiency For The Disassembly Of Modular Electronic Products," *Journal of Electronics Manufacturing*, Vol 9, No. 1, pp. 79-95, 1999.
[18] P. Veerakamolmal and S. M. Gupta, "Optimal Analysis Of Lot-Size Balancing For Multi-Products Selective Disassembly," *International Journal of Flexible Automation and Integrated Manufacturing*, Vol 6, No. 3-4, pp. 245-269, 1998.