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Research Article

AN INTEGER PROGRAMMING MODEL FOR DISASSEMBLY SYSTEM CONFIGURATION

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ABSTRACT

As the product life cycles have continuously decreased, disassembly system design has been regarded to be important for manufacturing enterprises. Effective design of a disassembly system enables the enterprises to recycle the end of life products with low cost and high utilization of labors. This study focuses on the line segmentation problem of disassembly system where the worker assignment and segment determination decisions are made simultaneously. To do so, higher utilization of worker resources is achieved and disassembly operations are carried out by effective worker teams since the worker timetabling and disassembly line segmentation problems taken into consideration concurrently. To represent the problem mathematically, an integer programming model is developed. Besides, two different heuristic procedures, namely SSGWA and CSGWA, are presented to solve the problem in a reasonable amount of time. According to the computational results, SSGWA heuristic superior to CSGWA heuristic consistently because it takes both line segmentation and worker assignment decisions into account simultaneously.

Keywords: Disassembly system configuration, line segmentation, worker assignment, effective worker teams.

1. INTRODUCTION

Product life cycle (PLC) consists of a set of stages in which the last stage corresponds to end of life (EOL) for every product. When a product is at the end of life phase, disassembly tasks can be performed in a disassembly system to enable the parts to be used in a different or the same product. It is called to be a product recovery operation. Product recovery is important for waste reduction and energy efficiency that affects sustainable manufacturing. Because of the diversity of customer needs, product life cycles are shortened and this paves the way for a disassembly system plays a major role in a reverse supply chain for rapid response to the needs (Srivastava, 2007). Disassembly has shown a major impact on material and product recovery in almost every product recovery attempt (Ozceylan et al. 2018).

A disassembly system comprised of several disassembly lines, such as straight and U-type lines, and each of which must be carried out in a workstation with a sequence to separate a product in its constituent parts (Desai and Mital, 2003). These workstations can be divided into segments for worker movement. Assigned workers perform these operations via a predetermined method. Effective determination of resource assignment across the system directly affects the

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output rates which are dependent on the resources used in the system. To operate the system effectively, right operational decisions, such as workforce assignment and line division into segments, must be made simultaneously. To do so, the disassembly system can be configured by taking resource constraints and throughput rates into account.

Disassembly system has taken a specific attention of researchers/practitioners and there is a considerable number of studies related to this system in the existing academic literature. There are three different main classes of problem: disassembly planning, disassembly scheduling, and disassembly line balancing (DLB) (Lee et al. 2001). The problems in these classes usually focus on the operational activities for disassembly systems. However, the design of the system is also important for finding effective solutions to these problems. For this reason, this study examines the design problem of disassembly system and the related studies are given in this section.

The main aim of designing studies is to minimize the number of workstations which are generated in a disassembly line to make the system efficient and economic. Tang et al. (2001) developed a two-phase holistic approach in which an algorithm is employed to divide a large system into smaller disassembly lines by dynamically configuring that incerases efficiency of the system. Through utilizing the approach, the specific needs of customers who have variant orders can be met. In this approach, the authors also presented an algorithm to balance the disassembly lines to maximize the outcome rates. Mascle (2002) proposed several algorithms to find a good sequence for a sub-assembly and a system life-cycle model by considering disassembly line design. They indicate that integration of disasembly operations can make valuable contribution in terms of repair, maintenance and recycle of products. Ohlendorf et al. (2004) extended the planning issue of disasembly system to include several aspects, such as in-plant logistic, storage and sorting applications. The main aim of their study is designing a economic and efficient disassembly system. To do so, they employed a simulation software by examining real industry sectors. Turowski et al. (2005) focused on uncertainty management in disassembly line design problem. They introduced a fuzzy coloured petri net model to highlight the factors that cause uncertainty. To cope with the uncertainties in the diassembly line, a heuristic approach was proposed while balancing the line. Sim et al. (2005) indicated that analyzing diassembly systems in the automotive industry is crucial to observe the opportunities for re-manufacturing. They proposed a novel disassembly system design for vehicle disassembly lines by evaluating four different existing system through simulation experiments. Xanthopoulos and Iakovou (2009) dealt with the design of revovery process, in other words diassembly process, of end-of-use electric and electronic goods. They introduced a tactical level problem and proposed a two-stage algorithm for the problem. In the first stage, an goal programming optimization model is developed to determine the end-of-life products to be recovered. In the second stage, a multi-period mixed integer linear programming optimization model is developed to focuse on recovery processes in order to minimize the lead time. Murata and Yura (2013) investigated the diassembly and sorting systems design problem and developed an integer programming formulation for the problem. The main aim is to find the number of stages, the number of stations in each stage and assignment of disassembly tasks to the stations. In order to represent the problem mathematically, an integer programming based optimization model was introduced and solved by CPLEX optimization solver. The results indicated that multistage parallel-station systems show better performance than multistage non-parallel and single stage parallel systems. Bentaha et al. (2014) proposed an approach to design the diassembly lines by maximizing the line profit under the assumption of the task times are stochastic with known probability distribution. They used Monte Carlo simulation method to deal with the uncertainties. Igarashi et al. (2014) developed an integer programming mathematical model for optimal design of disassembly system which is required by closed-loop supply chain. In the first stage the parts are determined for disassembly and the number of stations are minimized at the second stage. Steeneck et al. (2014) compared two different type of diassembly system configuration, namely standalone tear-down stations and diassembly lines. These configuration were analyzed for 8 different type of products under the assumption of uncertaion processing times. They showed the performance of configuration through several performance indicators, such as bottlenecks, use of resources, and throughpupt rates. Zhu and Roy (2015) addressed uncertainities for diassembly process planning and developed a framework to overcome uncertainty during the diassembly operations. Igarashi et al. (2016) mentioned that the environmental problems are important regarding the CO_2 emisions. They introduces a multi-criteria optimization problem so as to select environmental parts that saves CO_2 for disassembly system design and balancing. Pintzos et al. (2016) presented a method that employs product design files for the operational purposes in planning a disassembly system. The main concept in the method is disassembly precedence diagram generation algorithm that holds processing times for diassembly tasks. Mete et al. (2018) developed an optimisation model to design a hybrid system in which both assembly and disassembly tasks are taken into consideration. Bentaha et al. (2018) investigated the problem of disassembly line design with presence of hazardous parts and uncertainty of task processing time. Zhang and Chen (2018) examined the diassembly system in a holistic perspective by employing flexible transition technique. They carried out the simulation analysis to evaluate the scenario alternatives, which are created to investigate the problem in detail, and determine the best scenario for the disassembly system.

To the best of the authors' knowledge, while considering the relevant existing academic literature it is observed that there has not been any published study that focuses on line segmentation for disassembly system. For this reason, this study can be regarded to be the first attempt for this issue that is important to create efficient and economic disassembly lines. One of the main contributions of this study is to develop an integer programming model that helps to determine the segmentation of disassembly lines. In addition, worker timetabling decisions can be made by solving the same mathematical model and it can be evaluated as another main contribution of this study.

The rest of this paper is organized as follows. The problem description and lower bound for the problem are given in Section 2. The integer programming model is introduced in Section 3. Section 4 presents heuristic procedures which are employed to find good solutions to the problem. Section 5 provides concluding remarks and future research directions for the problem.

2. PROBLEM DESCRIPTION AND INTEGER PROGRAMMING MODEL

In this study, the disassembly system design problem is considered. This problem consists of determining the disassembly line segmentation where worker teams perform disassembly operations, worker assignment to jobs, and job scheduling. One of the main characteristics of the problem is that effective worker teams are constructed and these teams are employed into segments to expedite the disassembly operations. Once an effective worker team is constructed in a segment, the coefficient that directly affect the processing time can be determined. While the worker teams are determined, job scheduling decisions must be made to prevent the assignment of the same worker to different operations which are carried out simultaneously at different segments. The workers, who are assigned to the teams at a time period, can change their team through time. Assigning workers to different teams through time permits changes in processing times. The processing time of a job cannot be changed unless the worker teams are changed. An illustration for line segmentation and worker assignment to the segments is shown in Figure 1.

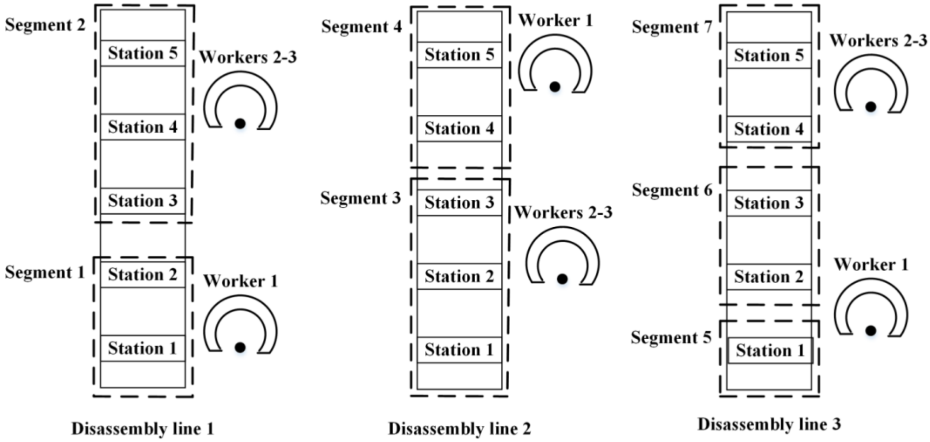

Figure 1. An illustration for segmentation of disassembly lines with the assignment of workers

Note that there are three different disassembly lines and each of them comprises five stations. The assignment of workers to the stations is made based on the segments at which workers perform the operations. As can be seen from figure 1, there is a worker pool and it consists of three workers. Once the disassembly line divided into segments, the workers are assigned to the segments from a worker pool and create worker teams which are changed through time. Since the assignment of the same worker to two different operations which are overlapped in time is not possible, worker assignment and operation sequence decisions have to be made simultaneously. For instance, since worker 1 is assigned to segments 1, 4, 5, and 6, and the disassembly operations carried out in these segments cannot be performed at the same time.

As described previously, the worker resource is one of the most widely used and valuable resources for the disassembly systems. The disassembly operations are performed to the end of use products, the companies cannot be willing to pay attention to those operations. It directly affects the resource amount which is assigned to those operations. Because it is difficult to carry out operations with a limited number of employees, the operation managers or industrial engineers should plan the resource in an effective way. This study aims to fill the gap in the academic literature in terms of workers planning problem in disassembly system. This problem deals with not only worker assignment but also line segmentation and job scheduling decisions. The problem is evaluated under the following assumptions.

The assumptions of the problem are as follows:

- The processing time of a disassembly operation in a segment is affected by the assigned worker team to this segment.
- All jobs are ready to be processed at time zero.
- The disassembly system consists of straight lines and the assignment of stations to the lines is known in advance.
- When a worker accomplishes his operation in a segment, he can move to another segment or he can continue in the same segment to carry out other operations.
- Setup times in any disassembly line are ignored.
- Each worker has a different set of skills for disassembly tasks.
- Each task is assigned to a station and these assignments are known in advance.
- Each segment consists of one or more station and just one operation is performed in each segment.
- Each operation consists of one or more tasks.

- Each line is divided into one or more segments.
- Each station contains at least one machine or equipment to be used for manual operations.

As explained before, there are four different decisions must be made: the sequence of jobs, the segmentation of lines, the worker assignment, and the starting time of operations. Since the objective is to minimize the maximum completion times, i.e. makespan, the finishing time of the last operation in each line must be decreased by creating effective worker teams that affect the processing time of operations carried out at the segments. Worker teams must be determined again when an operation is finished in a segment since a worker can be assigned to different operations, which means a different segment.

An integer programming optimization model is developed to mathematically express and find an optimal solution for the problem. The mathematical model is given in the next section.

2.1. Integer programming model

The indices, parameters, variables, and decision variables are as follows:

Indices

i: Index of workers (i=1,…,I)
j: Index of segments (j=1,…,J)
m: Index of stations (m=1,…,M)
b,d: Index of jobs (b,d=1,…,N)
k: Index of disassembly line (k=1,…,K)
t: Index of time (t=1,…,T)
$S1$: Set of segments
$S2$: Set of stations
$S3$: Set of jobs

Parameters

B: Large number
NP_b: Number of parts in job b
$a_{i,j}$: Processing time coefficient of worker i for segment j
$W_{,j}$: Maximum number of worker that can be assign to segment j

Variables

$Cmax$: Maximum completion time of all jobs (in other words makespan)
z_j: If one or more station is assign to segment j,1; otherwise, 0
c_b: Completion time of job b
p_b: Processing time of job b
f_{bd}: If starting time of job b is not larger than job d, 1; otherwise, 0
$f1_{bd}$: If completion time of job d is not larger than job b, 1; otherwise, 0
$x1_{ij}$: If worker i is assigned to segment j, 1; otherwise, 0
$cyc1_j$: Cycle time for segment j
cyc_k: Cycle time for line k
$t1_m$: Disassembly task time of station m

Decision variables

y_{m1}: If station m is assign to segment j; otherwise, 0
r_{bt}: If job b completes its operation at time t; otherwise, 0
o_{bd}: If operation of job b starts after job d, 1; otherwise, 0

x_{ib}: If worker *i* is assigned to job *b*, 1; otherwise, 0

Objective function

$$\text{Min } C\max \tag{1}$$

Constraints

$$\sum_{j\in S1_k} y_{mj} = 1 \quad m \in S2_k \tag{2}$$

$$\sum_{m\in S2_k} y_{mj} \le z_j \times B \quad j \in S1_k; k=1,...,K \tag{3}$$

$$\sum_{m\in S2_k} y_{mj} \ge z_j \quad j \in S1_k; k=1,...,K \tag{4}$$

$$y_{mj} \le z_j \quad j \in S1_k; m \in S2_k; k=1,...,K \tag{5}$$

$$y_{mj} \ge y_{nl} \quad j,l \in S1_k; m,n \in S2_k; k=1,...,K; n>m; l>j \tag{6}$$

$$\sum_{t=1}^{T} r_{bt} \times t = c_b \quad b=1,...,N \tag{7}$$

$$\sum_{t=1}^{T} r_{bt} = 1 \quad b=1,...,N \tag{8}$$

$$c\max \ge c_b \quad b \in S3_k; k=1,...,K \tag{9}$$

$$c_b \ge (c_d + p_d) - B \times (1 - o_{bd}) \quad b \in S3_k; d \in S3_k; k=1,...,K \tag{10}$$

$$p_b = cyc_k \times NP_b \quad b \in S3_k; k=1,...,K \tag{11}$$

$$cyc_k \ge cyc1_j \quad j \in S1_k; k=1,...,K \tag{12}$$

$$cyc1_j = t1_m \times \sum_{i=1}^{I} a_{i,j} \times x_{ij} \quad j \in S1_k; m \in S2_k; k=1,...,K \tag{13}$$

$$\sum_{i=1}^{I} x1_{ij} \ge 1 \quad j \in S1_k; k=1,...,K \tag{14}$$

$$\sum_{i=1}^{I} x1_{ij} \le W_j \quad j \in S1_k; k=1,...,K \tag{15}$$

$$x1_{ij} \ge x_{ib} \quad j \in S1_k; b \in S3_k; k=1,...,K \tag{16}$$

$$x_{ib} + x_{id} \le 3 - (f_{bd} + f1_{bd}) \quad b,d \in S3_k; i=1,...,I; k=1,...,K \tag{17}$$

$$(c_d - p_d) - (c_b - p_b) \le B \times f_{bd} \quad b,d \in S3_k; k=1,...,K \tag{18}$$

$$c_b - (c_d - p_d) \le B \times f1_{bd} \quad b,d \in S3_k; k=1,...,K \tag{19}$$

The objective function (1) aims to minimize the maximum of completion times, i.e. makespan. The makespan objective is an important indicator to show the performance of the system in terms of effective usage of resources. For this reason, the objective is determined as makespan in this study. The manufacturing lead time or the average lead time objectives can also be used to evaluate the performance of the system instead of makespan objective. The makespan objective can be replaced with the lead time objective for future research studies. Equation (2) states that each station must be assigned to one segment. Equations (3-5) ensure that at least one station must be assigned to a segment in order to utilize it. If there is not any assigned station to a segment, then this segment cannot be employed. The indicator variable z_j is used in these equations for the aforementioned purpose. To do so, neither there will not be any station which is not assigned to a segment nor there will not be any segment without at least one station is assigned to it. Equation (6) states that each job has a predetermined route in each line in which precedence relations cannot be violated. Equation (7) is utilized to compute the completion time of a job in a line. Equation (8) guarantees that each job must be completed at a time interval. Assignment of a worker to different operations that overlap in time is not possible by employing this equation in the optimization model. Equation (9) states that the makespan must be equal or greater than the maximum completion time of all jobs. Equation (10) is utilized to compute the completion and starting times of consecutive jobs which are assigned to the same line. Equation (11) is used to compute the processing time of a job. Equations (12-13) are employed to compute the time passed between two consecutive jobs in a segment, in other words cycle time. While determining the cycle time for a line, the processing time coefficient a_{ij} is considered in order to take the worker effect on processing time into account. Each worker in a team makes a negative or positive contribution to the coefficient that determines the processing time of operations in segments. Equations (14-15) state that at least one worker must be assigned to each segment and each segment has a capacity for worker assignment. Equation (16) ensures that once a worker is assigned to a job, the same worker must be assigned to the segment where the job is processed. Equations (17-19) guarantee that a worker is not assigned two different jobs overlapped in time. First, the time periods are determined by using time index t, then the equations are employed to prevent the assignment of workers different operations which are carried out at the same time period.

2.2. NP-hardness of the problem

When the problem is considered under the following assumption, the problem is reduced to the dynamic parallel machine flexible resource scheduling problem which is proved to be NP-hard in the academic literature (Edis et al. 2013).

- The disassembly lines are identical.
- The workers are identical.
- There is just one segment in each disassembly line.

It is clear that the investigated problem is also NP-hard in the strong sense with the extra set of hard constraints. Because the computational complexity of the proposed integer programming model leads to computational burden and finding optimal solutions requires high computational time for large-sized problems, using heuristic approaches is reasonable for the investigated problem. For this reason, we proposed two different heuristic approaches to solve the problem in a reasonable amount of time.

2.3. Lower bound

The following equation is developed for the lower bound (LB).

Theorem 1

$LB = \sum_{b=1}^{N} \left\lceil \frac{p_b}{K} \right\rceil$ where a_{ij}=0 $\forall i, j$

Proof

If we assume that there exist a solution value *C1max* which is smaller than *LB*. We know that there are equations $p_b = cyc_k \times NP_b \quad b \in S3_k; k = 1,\ldots,K$, $cyc_k \geq cyc1_j \quad j \in S1_k; k = 1,\ldots,K$, $cyc1_j = cyc2_j \times \sum_{i=1}^{I} a_{i,j} \times x_{ij} \quad j \in S1_k; k = 1,\ldots,K$ to compute the processing time of a job. There is not any case that each worker has full capacity a_{ij}=0. Since these equations are obviously contradict with *C1max* < *LB*, the proposed equation $LB = \sum_{b=1}^{N} \left\lceil \frac{p_b}{K} \right\rceil$ is used to be lower bound for the problem.

3. HEURISTIC ALGORITHMS

In this section, two heuristic algorithms are presented by considering several aspects of the problem. Since the problem consists of determining the segments and worker assignment to the segments, heuristic algorithms must take into account these decisions. That being the case, the first heuristic is developed with stage-wise fashion and the second heuristic find reasonable solutions for the segment generation and worker assignment simultaneously.

3.1. Heuristic algorithms

In this section, two different heuristic algorithms are introduced. While simultaneous segment generation worker assignment (SSGWA) heuristic is developed, decisions are made by considering the availability of workers and best possible segments are determined for the worker teams. The reason for using these two heuristics is that each heuristic fills the gap left by the other heuristic to solve the problem. Because the problem is NP-hard, an efficient algorithm must be developed to solve the problem. One-way to develop this type of algorithm is that examining the problem from the structural properties. When the properties of the problem are investigated, it is revealed that there are two main structures of the problem at which the heuristic algorithms correspond to. That is why; these two heuristic algorithms are employed to find high-quality solutions for the problem.

These two heuristics can be considered as the main contribution of the paper in which disassembly system configuration is investigated from these perspectives for the first time in the academic literature according to the best of the author’ knowledge.

The SSGWA heuristic starts with assigning jobs to the corresponding lines, then the segment efficiency is calculated to determine the segments and assign the workers to the segments in an efficient way. The workers are assigned to the jobs, which are performed into the segments, and the worker teams are determined with the segmentation. For each job, this cycle is repeated again until all the jobs are processed on the disassembly lines. As it can easily be seen from the SSGWA heuristic, worker assignment and segment generation decisions are made simultaneously.

The SSGWA heuristic is employed to find the values for decision variable simultaneously. However, concurrent segment generation worker assignment (CSGWA) heuristic first consider the workers who will be assigned to the lines and then the segmentation of the lines in which disassembly operations are performed. While the segment efficiency is an evaluation rule to assign workers to the segments for SSGWA heuristic, it is not applied to the CSGWA heuristic.

The step of SSGWA heuristic is elucidated as follows:

(1) **for** b=1:N
(2) **for** k=1:K
(3) Assign job b to corresponding line k
(4) Determine first m (number of station in line k) worker who reduce the processing time to the lowest level
(5) Compute the segment efficiency by summing the processing time coefficient of workers a_{ij}
(6) Divide line k into segments by considering minimum $\sum_{i=1}^{m} a_{ij}$ value
(7) Assign workers to the constructed segments for job b
(8) **end**
(9) **for i=1:I**
(10) **If** worker i assign to line k and k-1, then wait for finishing of the job assigned to line k-1
(11) **else** continue the operation of the job b in line k
(12) **end**
(13) **end**
(14) **end**

The CSGWA heuristic starts with the determination of segments by computing the efficiency values, after the segmentation decisions the workers are assigned to the jobs and implicitly to the segments.

The step of CSGWA heuristic is elucidated as follows:

(1) Randomly assign the same number of workers to the lines from the worker pool
(2) **for** b=1:N
(3) **for** k=1:K
(4) Assign job b to corresponding line k
(5) Divide line k into segments by considering minimum $\sum_{i=1}^{m} a_{ij}$ value
(6) **end**
(7) **for i=1:I**
(8) **If** worker i assign to line k and k-1, then wait for finishing of the job assigned to line k-1
(9) **else** continue the operation of the job b in line k
(10) **end**
(11) **end**
(12) **end**

4. EXPERIMENTAL RESULTS

In this section, the proposed heuristic algorithms are employed for solving disassembly line segmentation along with worker assignment and job scheduling problems. For comparison purpose, the experimental data set is randomly generated based on a real disassembly line from the home appliance industry. The generated test samples for small- and large-sized problems are shown in Table 1.

A benchmark of 9 test problems is obtained and each problem is solved 5 times with different random seeds for each heuristic to make comparison fairer. By doing this, the understandability of the results is enhanced and it paves the way for revealing the covered impacts of the number of workers, number of lines and the number of jobs on the maximum of the completion time.

Table 1. Parameters setting

Parameter	Description	Value
nw	Number of workers	3-6-9
nl	Number of lines	2-4-6
nj	Number of jobs	U[5, 15]
np	Number of parts	U[5, 10]
pt	Processing time	U[5, 50]

The relative percentage deviation (RPD) ratio is considered to be evaluation metric for comparison purpose and it is most widely accepted evaluation metric in the academic literature especially when the heuristic and meta-heuristic algorithms are compared. The reason of why the percentage deviation is not employed for comparison is that the obtained percentages are so large which makes the comparison harder.

$$RPD = \frac{solution - LB}{solution} \tag{19}$$

The average and maximum relative percentage deviation ratios are shown in table 2 for each heuristic, respectively.

After the heuristics are employed to the generated instances, the results are obtained and shown in Table 2. According to the results, SSGWA heuristic outperforms CSGWA heuristic for all problems. The computational results give an insight about which algorithms outperform to the other.

Table 2. Computational results

			SSGWA		CSGWA	
No.	nw	nl	Ave. RPD	Max. RPD	Ave. RPD	Max. RPD
1	3	2	11%	13%	14%	17%
2	3	4	11%	14%	13%	17%
3	3	6	13%	15%	16%	18%
4	6	2	10%	11%	12%	12%
5	6	4	14%	16%	16%	18%
6	6	6	14%	16%	16%	18%
7	9	2	9%	11%	10%	12%
8	9	4	16%	18%	17%	18%
9	9	6	18%	19%	19%	21%

To evaluate the performance of the heuristics with respect to each other, RPD ratios are considered in two different manners, namely Ave. RPD and Max. RPD. These results indicate that deviation from the lower bound is large for both heuristics and it can be caused by either heuristic or lower bound. Since the main aim of this section is to compare heuristics, the large deviation from lower bound is not investigated in this section. This question can be the research topic for future studies. When the heuristics are compared with each other it is obvious that there is not a significant difference between them. However, SSGWA heuristic shows better performance than CSGWA heuristic for each instance regarding the performance. It can also be observed from figure 2 easily.

The SSGWA heuristic shows the best performance for problem seven in which the number of workers is equal to nine and the number of lines is equal to two. It means that the SSGWA heuristic performs better when the number of lines is at their minimum level and the number of workers is at their maximum level. The SSGWA heuristic gives the worst results when the number of workers is equal to nine and the number of lines is equal to 6. It indicates that the SSGWA heuristic is a promising one especially when the number of lines is at the minimum level. The SSGWA heuristic is proposed for the problem under several assumptions so that it is able to be improved by extracting some assumption for real-manufacturing cases. The same results are observed from Table 2 for the CSGWA heuristic and it means that the parameters have a similar effect on the performances of heuristics.

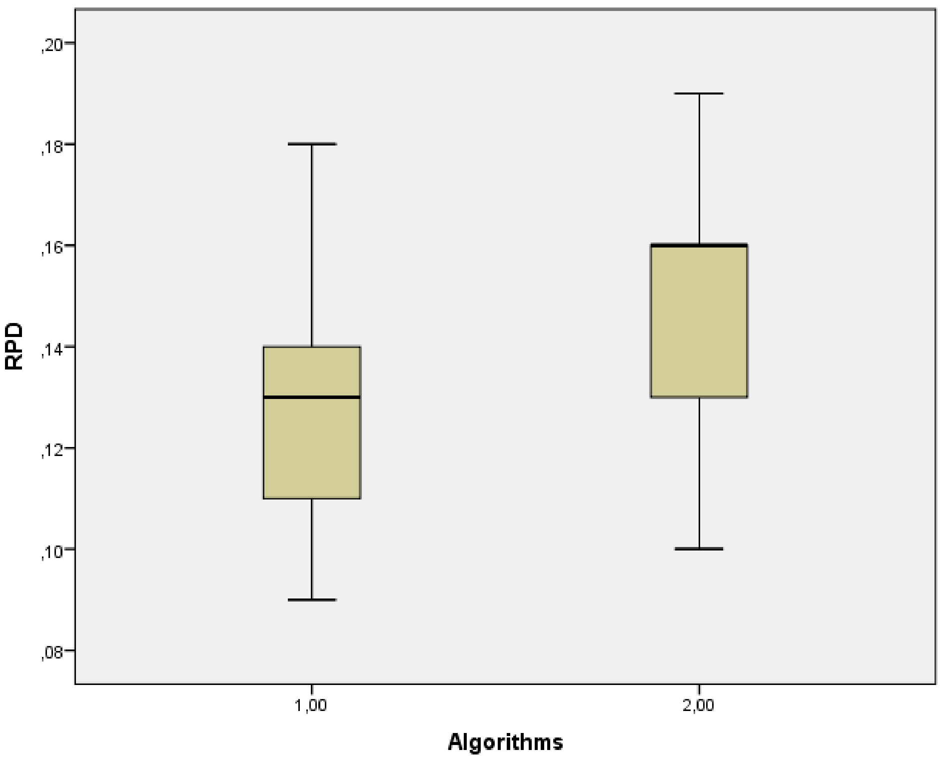

Figure 2 Box-plot of RPD values with respect to algorithms (SSGWA-1; CSGWA-2)

As it is indicated before, the SSGWA heuristic outperforms the CSGWA heuristic and it is shown in figure 2. The box-plot comparison reveals that there is not any statistically significant difference between algorithms; however, it can also be concluded that if the box-plot coverage is less than the other, this algorithm can be accepted as better one.

The figure obviously shows that the intervals overlap with each other when all problems are considered at the same time, however mean values of the intervals are slightly overlap and it supports the conclusion which is reached before that The SSGWA heuristic is superior than CSGWA heuristic.

5. CONCLUSIONS

The increasing needs of effective segmentation of disassembly system and utilization of worker resource within the system have prompted active research in the disassembly systems over the last decade. In order to the best use of resources, such as workers and equipment, disassembly line segmentation and worker timetabling problems should be examined together with the job scheduling problem. In this paper, we model the disassembly system design problem considering the line segmentation, worker assignment, and job scheduling to minimize makespan. Through the effective utilization of all resource types (especially worker resource), makespan can be decreased considerably.

Reasonable resource utilization is one of the core design problems of the disassembly system especially when it is evaluated with the segmentation of disassembly line. For this reason, we focused on disassembly system design problem that comprised of the line segmentation, worker assignment, and job scheduling problems. Since the considered design problem has been shown as NP-hard in the strong sense, two heuristic procedures have been employed and compared with each other. For the comparison purposes, computational experiments are carried out utilizing a set of instances which are generated based on a real disassembly line.

The computational results show that the SSGWA heuristic superior to the CSGWA heuristic for each kind of instance. According to the results, it can be concluded that better RPD results can be reached when simultaneous worker assignment, segmentation, job scheduling decisions are made with respect to concurrent decisions.

Future research studies should investigate stochastic or fuzzy processing times for jobs. In addition, the skill levels of workers can be examined from a different perspective in detail, such as skill levels. As indicated in section 2.1, the mathematical model and the heuristic algorithms can be solved with the lead time objective instead of the makespan objective. Last but not least, the disassembly line segmentation problem can be extended to different re-manufacturing environment.

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