VOL. 11, NO. 10, MAY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences
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# THE IMPROVEMENT OF LINE EFFICIENCY ON DISASSEMBLY LINE BALANCING PROBLEM: AN HRRCD'S HEURISTIC RULE

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## ABSTRACT
Disassembly line balancing problem (DLBP) is the factor of remanufacturing industry to improve their effectiveness on part demand. The application of HRRCD's (Hazard-Reuse-Recycle-Collected-Disposed) heuristic rule will solve the problem of disassembly line by improving the line efficiency and reducing balance delay. A case study from truck's remanufacturing industry will apply the heuristic rule, which it will improve disassembly line efficiency and decline idle time. Observation from real truck disassembly line will apply in time study and the results show that HRRCD based disassembly line balancing method is the best method to optimize the truck's disassembly line.

**Keywords:** disassembly line balancing problem, remanufacturing, line efficiency, idle time.

## INTRODUCTION
Remanufacturing is an industrial process in which worn-out products are restored to like-new product's conditions. Thus, remanufacturing provides the quality standards of new product with used parts (McGovern and Gupta, 2003a). In order to minimize the amount of waste sent to landfills, product recovery seeks to obtain materials and component from old or outdated products through recycling and remanufacturing. This includes the reuse of components and products. There are many attributes of a product that enhance product recovery such as ease of disassembly, modularity, type and compatibility of materials used, material identification markings, and efficient cross-industrial reuse of common parts/materials. The first crucial step of product recovery is disassembly (McGovern and Gupta, 2004a).

Recently, disassembly has gained a great deal of attention in the literature due to its role in product recovery. A disassembly system faces many unique challenges; for example, it has significant inventory problems because of the disparity between the demands for certain parts or subassemblies and their yield from disassembly. The flow process is also different. As opposed to the normal "convergent" flow in regular assembly environment, in disassembly the flow process is "divergent" (a single product is broken down into many subassemblies and parts). There is also a high degree of uncertainty in the structure and the quality of the returned product. The conditions of the products received are usually unknown and the reliability of the components is suspects. Some parts of the product may cause pollution or may be hazardous. These parts tend to have a higher chance of being damaged and hence may require special handling, which can also influence the utilization of the disassembly workstations. For example, an automobile slated for disassembly contents a variety of parts that are dangerous to remove and/or present a hazard to the environment such as the battery, airbags, fuel and oil. Various demanded sources may also lead to complications in disassembly line balancing. The reusability of parts creates a demand for these parts, however, the demands and availability of the reusable parts is significantly less predictable than what is found in the assembly process. Finally, disassembly line balancing is critical in minimizing the use of valuable recourses (such as time and money) invested in disassembly and maximizing the level of automation of the disassembly and the quality of the parts (or material) removed (McGovern and Gupta, 2003a).

## DISASSEMBLY LINE BALANCING

### Introduction of disassembly line balancing
The basic disassembly line balancing problem (DLBP) can be stated as the assignment of disassembly tasks to an ordered sequence of stations such that various forms of precedence relations are satisfied and some measure of effectiveness is optimized. Due to long term effect of the balancing decisions, the objective has to be chosen carefully considering the strategic goals of the enterprise (Becker and Scholl, 2003). Commonly studied objectives include minimizing number of stations given cycle time, maximizing production rate (equivalently minimizing cycle time) given number of stations, maximizing the line efficiency (directly depends on the number of stations and cycle time, cost minimization and profit maximization. Profit seeking nature of disassembly systems should be taken into consideration in choosing the objective for DLBP.

### Mathematical model of disassembly line balancing
According to McGovern and Gupta (2011), the mathematical foundations for the research of the Disassembly Line Balancing Problem (DLBP) have been discussed and then each of these is generated using formulae. These formulae are essential in enabling line efficiency analysis with proposed HRRCD heuristic rule.
The formulae to calculate Workstation Idle Times as below:

VOL. 11, NO. 10, MAY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences
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Workstation Idle Times, *I*

$$I = (NWS \times CT) - \sum_{k=1}^{n} PRT_k \quad (1)$$

Or

$$I = \sum_{j=1}^{NWS} (CT - ST_j) \quad (2)$$

CT = Cycle Time
ST = Standard Time
NWS = Number of Workstations
PRT = Part Removal Times

Standard Time, ST

$$= \frac{\sum NT}{1 - AF} \quad (3)$$

AF – Allowance Factor

Cycle Time, CT

$$= \frac{Disassembly\ Time\ available\ per\ day}{Parts\ disassembled\ per\ day} \quad (4)$$

Line Efficiency, E

$$= \frac{\sum TT}{(NWS)(CT)} \quad (5)$$

TT = Task Time

**Research methodology**

During this research, both qualitative and quantitative method used. Qualitative research method involve a recondition and rebuilt truck factory as case study and interview between researcher and top management of the truck remanufacturer was conducted several times. At the same time, observation of the disassembly line of dismantle truck was conducted, times will be recorded using stop watch. For quantitative research method, this research will use mathematical model and apply HRRCD (Hazard-Reuse-Recycle-Collected-Disposed) heuristic rule to analyze data gathered from observations through the disassembly line.

According to the flow chart for research methodology in Figure-1, the design for experiment used mathematical model and HRRCD heuristic rule to find the optimum line balancing. The experiment involve collection of primary data like questionnaire and interviews as well as time study. Secondary data like records of past performance also used in this research.

When primary and secondary data are collected, the data collected will analyze by applying mathematical model as well as HRRCD heuristic rule. The output of the analysis will proposed to the truck remanufacturer for satisfaction. Truck remanufacturer satisfied with the result and a full report will submit to top management of truck remanufacturer.

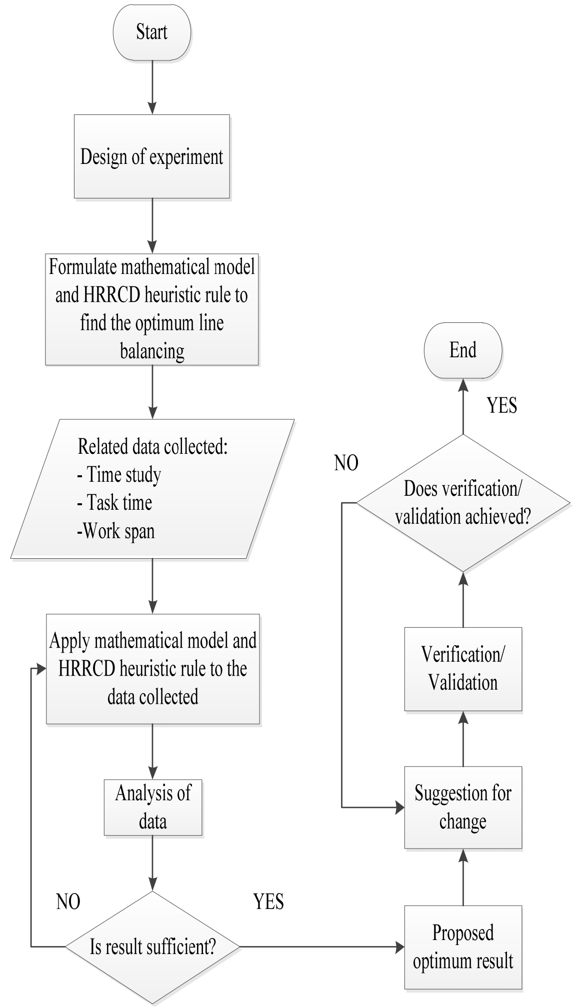


**Figure-1.** Research methodology.

The methods used for analyzing all the information and data is mathematical model and apply HRRCD (Hazard-Reuse-Recycle-Collected-Disposed) heuristic rule to analyze data gathered from observations through disassembly line and Direct Time Study used during observation processed. For Direct Time Study, it will be used to calculate Normal Time (NT) and Standard Time (ST).

**Research finding and decision**

The company's process for disassembly is as shown in Figure-2.

Time study was carried out for current situation and the results are as shown below. The time was taken using a stop watch.

From equation (3), the standard time is calculated.

Daily disassembly, (Dd) = 5 parts
Daily working hour, (Dw) = 8.5 hours

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According to Human Resource Department, assumption of Worker allowance = 15%

Normal Time, NT = 993.565 minutes
Standard Time, ST = TNT/ (1-Allowance)
= 993.565 / (1-0.15)
= 993.565 / 0.85
= 1168.9 minutes
From equation (4), the cycle time is calculated.
Cycle Time, CT = Dw/ Dd
= (8.5 x 60 minutes) / 5
= 510 minutes /5
= 127.5 minutes

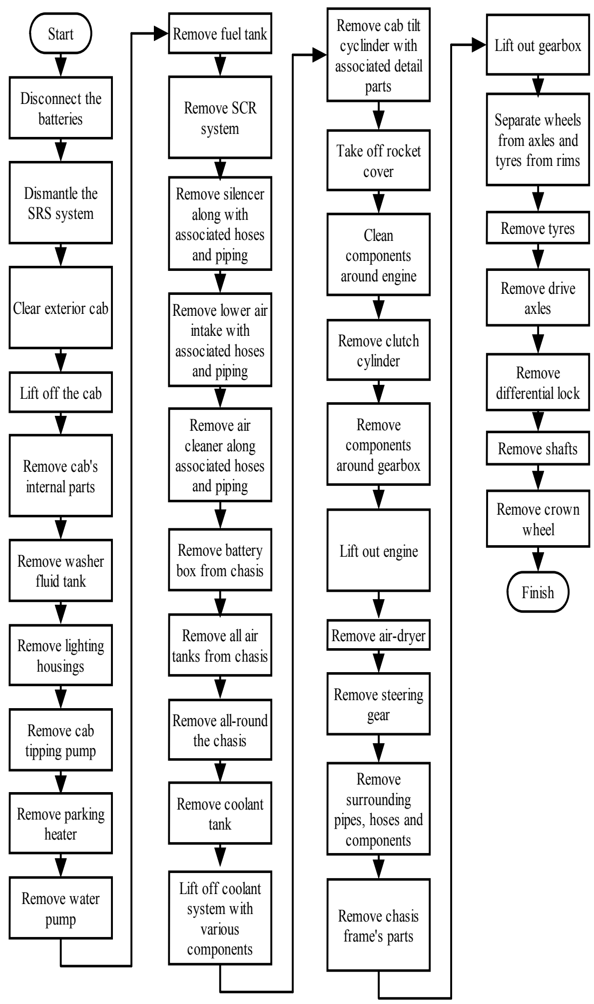


**Figure-2.** The flow chart of truck disassembly line.

The above results are for standard time and cycle time. The precedence diagram is as in Figure-3.

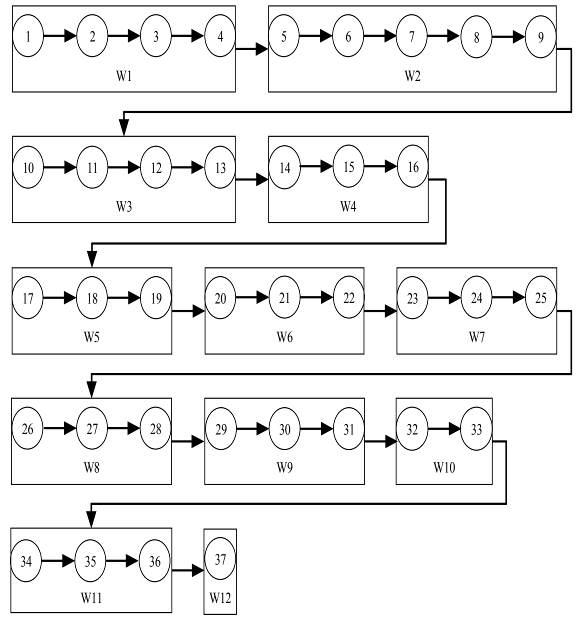


**Figure-3.** The precedence diagram of current truck's disassembly line.

**Table-1.** Work elements performed by worker in each station.

| Workstation | Work Elements | Standard Time (ST, minutes) | Total Station Time (TTS, minutes) |
|---|---|---|---|
| 1 | 1 | 5 | 5 |
| | 2 | 31.3 | 36.3 |
| | 3 | 31.2 | 67.5 |
| | 4 | 52.9 | 120.4 |
| 2 | 5 | 56.6 | 56.6 |
| | 6 | 10 | 66.6 |
| | 7 | 14.4 | 81 |
| | 8 | 14.4 | 95.4 |
| | 9 | 15.6 | 111 |
| 3 | 10 | 31.1 | 31.1 |
| | 11 | 15.6 | 46.7 |
| | 12 | 21.2 | 67.9 |
| | 13 | 59.3 | 127.2 |
| 4 | 14 | 58.5 | 58.5 |
| | 15 | 31.4 | 89.9 |
| | 16 | 31.8 | 121.7 |
| 5 | 17 | 31.4 | 31.4 |
| | 18 | 31.3 | 62.7 |
| | 19 | 11.7 | 74.4 |
| 6 | 20 | 65 | 65 |
| | 21 | 33.2 | 98.2 |
| | 22 | 5 | 103.2 |
| 7 | 23 | 34 | 34 |
| | 24 | 10.7 | 44.7 |
| | 25 | 31.3 | 76 |
| 8 | 26 | 55.1 | 55.1 |
| | 27 | 35.1 | 90.2 |
| | 28 | 13.4 | 103.6 |
| 9 | 29 | 33.8 | 33.8 |
| | 30 | 33 | 66.8 |
| | 31 | 58.2 | 125 |
| 10 | 32 | 58.4 | 58.4 |
| | 33 | 15 | 73.4 |
| 11 | 34 | 55.5 | 55.5 |
| | 35 | 31.8 | 87.3 |
| | 36 | 32.3 | 119.6 |
| 12 | 37 | 13.4 | 13.4 |

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Line Efficiency, E = 1168.9 / (w*x Tc)
= 1168.9 / (12 x 127.5)
= 1168.9 / 1530
= 0.764 @ 76.4%

Idle Time, I = (NWS x CT) - ∑PRT
= (12 x 127.5) – 1168.9
= 1530 – 1168.9
= 361.1 minutes

Balance Delay, d = I / (NWS x CT)
= 361.1 / 1530
= 0.236 @ 23.6%

The HRRCD is now applied to reduce the idle time. The collected data is put through HRRCD heuristic process to find improvement in disassembly line balancing. The results of the process is tabulated as in Table-1. The outcome of the heuristic rules is tabulated in Table-2. The resultant idle time after application of HRRCD is as shown:

**Table-2.** Work elements of truck's disassembly line with HRRCD heuristic rule.

| | | HRRCD Heuristic Rule | | | | |
|---|---|---|---|---|---|---|
| Work Element | Standard Time (ST, minutes) | Hazard | Recycle | Reuse | Collected | Disposed |
| 1 | 5 | √ | | √ | √ | |
| 2 | 31.3 | | √ | √ | √ | |
| 3 | 31.2 | | √ | √ | √ | |
| 4 | 52.9 | | √ | √ | √ | |
| 5 | 56.6 | | √ | √ | √ | |
| 6 | 10 | | √ | √ | | |
| 7 | 14.4 | | √ | √ | √ | |
| 8 | 14.4 | | √ | √ | √ | |
| 9 | 15.6 | | √ | √ | √ | |
| 10 | 31.1 | | √ | √ | √ | |
| 11 | 15.6 | | √ | √ | √ | |
| 12 | 21.2 | | √ | √ | √ | |
| 13 | 59.3 | | √ | | | √ |
| 14 | 58.5 | | √ | | | √ |
| 15 | 31.4 | | √ | | | √ |
| 16 | 31.8 | | √ | √ | √ | |
| 17 | 31.4 | | | √ | √ | |
| 18 | 31.3 | | √ | √ | √ | |
| 19 | 11.7 | | √ | √ | √ | |
| 20 | 65 | | √ | √ | √ | |
| 21 | 33.2 | | √ | √ | √ | |
| 22 | 5 | | √ | √ | √ | |
| 23 | 34 | | √ | √ | √ | |
| 24 | 10.7 | | √ | √ | √ | |
| 25 | 31.3 | | √ | √ | √ | |
| 26 | 55.1 | | √ | √ | √ | |
| 27 | 35.1 | | | √ | | |
| 28 | 13.4 | | √ | | √ | |
| 29 | 33.8 | | | √ | √ | |
| 30 | 33 | | | √ | √ | |
| 31 | 58.2 | | √ | √ | √ | |
| 32 | 58.4 | | √ | √ | √ | |
| 33 | 15 | | √ | √ | √ | |
| 34 | 55.5 | | √ | √ | √ | |
| 35 | 31.8 | | √ | √ | √ | |
| 36 | 32.3 | | √ | √ | √ | |
| 37 | 13.4 | | √ | √ | √ | |

**Table-3.** Work elements performed by worker in each station with HRRCD heuristic rule.

| Workstation | Work Elements | Standard Time (ST, minutes) | Total Station Time (TTS, minutes) |
|---|---|---|---|
| 1 | 1 | 5 | 5 |
| | 2 | 31.3 | 36.3 |
| | 3 | 31.2 | 67.5 |
| | 4 | 52.9 | 120.4 |
| 2 | 5 | 56.6 | 56.6 |
| | 6 | 10 | 66.6 |
| | 7 | 14.4 | 81 |
| | 8 | 14.4 | 95.4 |
| | 9 | 15.6 | 111 |
| | 11 | 15.6 | 126.6 |
| 3 | 10 | 31.1 | 31.1 |
| | 12 | 21.2 | 52.3 |
| | 13 | 59.3 | 111.6 |
| 4 | 14 | 58.5 | 58.5 |
| | 15 | 31.4 | 89.9 |
| | 16 | 31.8 | 121.7 |
| 5 | 17 | 31.4 | 31.4 |
| | 21 | 33.2 | 64.6 |
| | 23 | 34 | 98.6 |
| | 24 | 10.7 | 109.3 |
| 6 | 18 | 31.3 | 31.3 |
| | 19 | 11.7 | 43 |
| | 20 | 65 | 108 |
| | 22 | 5 | 113 |
| 7 | 25 | 31.3 | 31.3 |
| | 26 | 55.1 | 86.4 |
| | 27 | 35.1 | 121.5 |
| 8 | 29 | 33.8 | 33.8 |
| | 30 | 33 | 66.8 |
| | 31 | 58.2 | 125 |
| 9 | 28 | 13.4 | 13.4 |
| | 32 | 58.4 | 71.8 |
| | 33 | 15 | 86.8 |
| | 35 | 31.8 | 118.6 |
| 10 | 34 | 55.5 | 55.5 |
| | 36 | 32.3 | 87.8 |
| | 37 | 13.4 | 101.2 |

Line Efficiency, E = 1168.9 / (w*x Tc)
= 1168.9 / (10 x 127.5)
= 1168.9 / 1275
= 0.917 @ 91.7%

Idle Time, I = (NWS x CT) - ∑PRT
= (10 x 127.5) – 1168.9
= 1275 – 1168.9
= 106.1 minutes

Balance Delay, d = I / (NWS x CT)
= 106.1 / 1275
= 0.083 @ 8.3%

The precedence diagram is also drawn as in Figure-4.

VOL. 11, NO. 10, MAY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences
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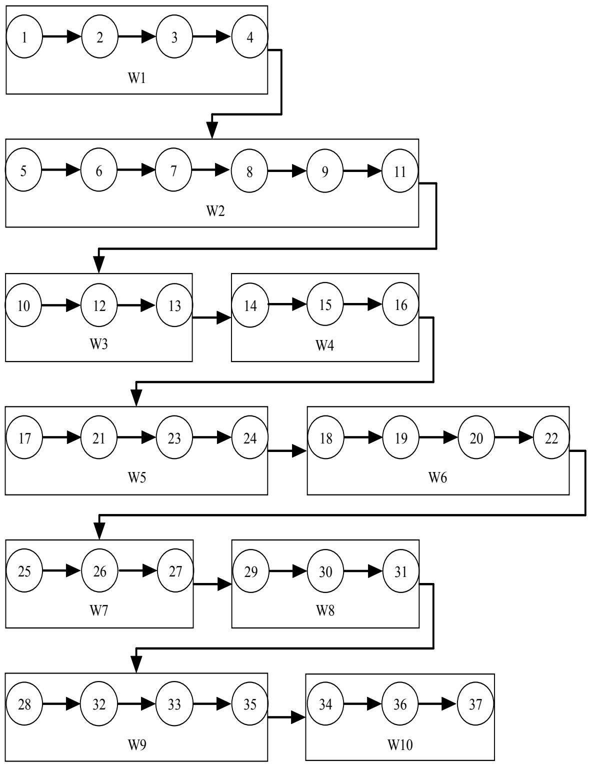


**Figure-4.** The precedence diagram of truck's disassembly line by using HRRCD heuristic rule.

**Comparison of before and after HRRCD**

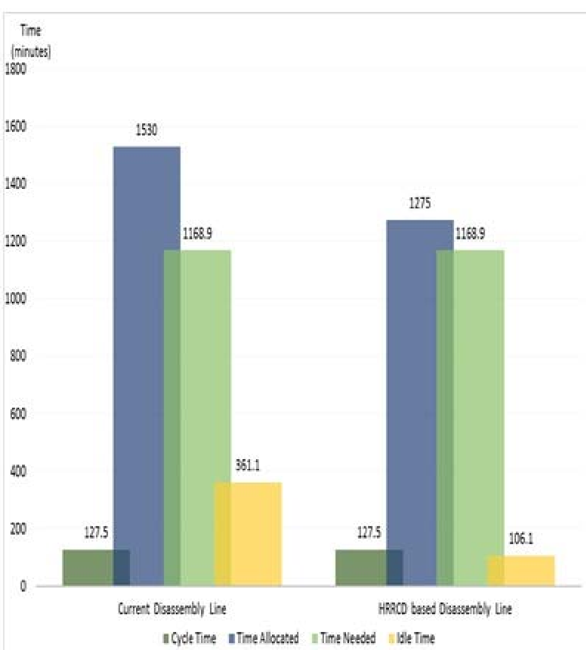


**Figure-5.** Bar chart of the cycle time, time allocated, time needed, and idle time.

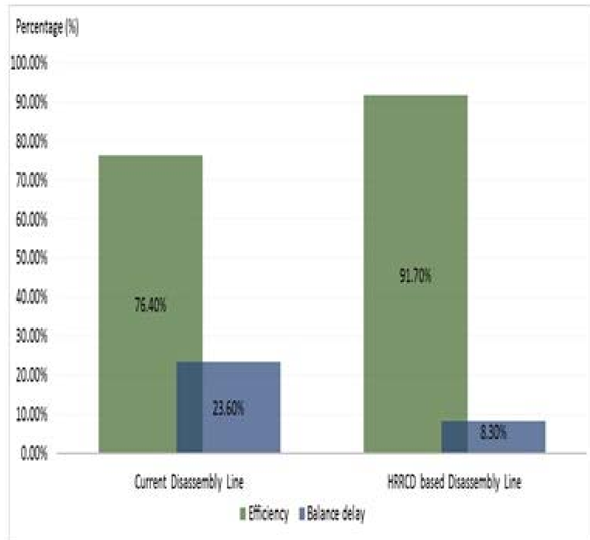


**Figure-6.** Bar chart of the line efficiency and balance delay.

The cycle time for current disassembly line was 127.5 minutes (Figure-5). Time allocated for current disassembly line was 1530 minutes and time needed was 1168.9 minutes. Total idle time for current disassembly line was 361.1 minutes. In Figure-6, the line efficiency of current disassembly line was achieved 76.4% and balance delay was 23.6%.

In Figure-5, the bar chart shows 4 elements of disassembly line balancing which is cycle time, time allocated, time needed, and idle time for HRRCD based disassembly line. For HRRCD based disassembly line, the cycle time is 127.5 minutes. In term of time allocated, HRRCD based disassembly line allocate 1275 minutes. Time needed for HRRCD based disassembly line is 1168.9 minutes. Next, the idle time for HRRCD based disassembly line is 106.1 minutes. In Figure 6, the line efficiency of HRRCD based disassembly line was increase to 91.7% and reduce the balance delay to 8.3%.

The HRRCD based disassembly line method was selected as the best method in disassembly line balancing because it's systematically arranging the workstations that create the highest line efficiency in the truck's disassembly line industry. When compared to 2-opt heuristic by McGovern and Gupta (2003a), the HRRCD heuristic shows better result. If compared to current disassembly line, the proposed HRRCD based disassembly line method creates more efficient in truck disassembly process because it creates the highest line efficiency and least idle time and balance delay. At the same time, the proposed HRRCD based disassembly line method classified all parts from disassembly process to material handling process, which distribute parts according to HRRCD (Hazard-Reuse-Recycle-Collected-Disposal) heuristic rule. Truck's disassembly factory operators save a lot of time in classifying parts after disassembled. When

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disassembly time is reduced, definitely cost to disassemble will decrease too. This prove that HRRCD can be used to optimize the truck's disassembly line balancing.

## CONCLUSIONS

The proposed HRRCD based disassembly line method is more efficient if compared to the current disassembly line. The proposed HRRCD based disassembly line method is easier to apply and has higher productivity (increase 15.3% of efficiency), lower workstation (reduce 2 workstations), and lesser idle time (reduce 255 minutes). According to remanufacturing expertise, the disassemblers adopted proposed HRRCD based disassembly line method will affect work elements that assigned to each workstations even more systematically as well as organized. The disassemblers, at the same time, they will classified and verified each part from disassembly process through material handling to material classification. They will save more time during remanufacturing process such as reuse for certain automotive parts. As the result, the proposed HRRCD based disassembly line method is a better remanufacturing's choice, which optimize the line efficiency and cost as well as time.

## REFERENCES

[1] Becker,C.andScholl,A.(2003).A survey on problems and methods in generalized assembly line balancing, Working paper, Friedrich-Schiller-Universitat Jena, Jena,Germany.

[2] McGovern, S., & Gupta, S. M. (2003a). 2-opt heuristic for disassembly line balancing problem. In Proceedings of the SPIE international conference on environmentally conscious manufacturing III (pp. 71¨C84). Providence, Rhode Island.

[3] McGovern, S., & Gupta, S. M. (2003b). Greedy algorithm for disassembly line scheduling. In Proceedings of the 2003 IEEE international conference on systems, man, and cybernetics (pp. 1737¨C1744). Washington, DC.

[4] McGovern, S. M. and Gupta, S. M. (2004a). "Combinatorial Optimization Methods for Disassembly Line Balancing." Proceedings of the 2004 SPIE International Conference on Environmentally Conscious Manufacturing IV, Philadelphia, Pa., 53–66.

[5] McGovern, S. M. and Gupta, S. M. (2004b). "Demanufacturing Strategy Based Upon Metaheuristics." Proceedings of the 2004 Industrial Engineering Research Conference, Houston, Tex., CD-ROM.

[6] McGovern, S. M. and Gupta, S. M. (2004c). "Metaheuristic Technique for the Disassembly Line Balancing Problem." Proceedings of the 2004 Northeast Decision Sciences Institute Conference, Atlantic City, N.J., 223–225.

[7] McGovern, S. M. and Gupta, S. M. (2004d). "Multi-criteria Ant System and Genetic Algorithm for End-of-Life Decision Making." Proceedings of the 35th Annual Meeting of the Decision Sciences Institute, Boston, Mass., 6371–6376.

[8] McGovern, S.M. and Gupta, S.M., "The Disassembly Line: Balancing and Modeling", McGraw Hill, New York, ISBN: 9780071622875, 2011.