This article was downloaded by: [185.55.64.226]
On: 15 March 2015, At: 01:22
Publisher: Taylor & Francis
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK

International Journal of Occupational Safety and Ergonomics
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tose20

Heuristic Procedure for the Assembly Line Balancing Problem With Postural Load Smoothness

Chorkaew Jaturanonda[a], Suebsak Nanthavanij[b] & Sanchoy K. Das[c]

[a] Department of Production Engineering, King Mongkut's University of Technology Thonburi, Bangkok, Thailand

[b] Engineering Management, Sirindhorn International Institute of Technology, Thammasat University, Pathum Thani, Thailand

[c] Department of Mechanical and Industrial Engineering, New Jersey Institute of Technology, Newark, USA

Published online: 08 Jan 2015.

To cite this article: Chorkaew Jaturanonda, Suebsak Nanthavanij & Sanchoy K. Das (2013) Heuristic Procedure for the Assembly Line Balancing Problem With Postural Load Smoothness, International Journal of Occupational Safety and Ergonomics, 19:4, 531-541

To link to this article: http://dx.doi.org/10.1080/10803548.2013.11077017

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the "Content") contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at http://www.tandfonline.com/page/terms-and-conditions

International Journal of Occupational Safety and Ergonomics (*JOSE*) 2013, Vol. 19, No. 4, 531–541

Heuristic Procedure for the Assembly Line Balancing Problem With Postural Load Smoothness

Chorkaew Jaturanonda

Department of Production Engineering, King Mongkut's University of Technology Thonburi, Bangkok, Thailand

Suebsak Nanthavanij

Engineering Management, Sirindhorn International Institute of Technology, Thammasat University, Pathum Thani, Thailand

Sanchoy K. Das

Department of Mechanical and Industrial Engineering, New Jersey Institute of Technology, Newark, USA

This paper presents a heuristic procedure for assigning assembly tasks to workstations where both productivity and ergonomics issues are considered concurrently. The procedure uses Kilbridge and Wester's algorithm to obtain an initial task–workstation assignment solution which minimizes the balance delay of an assembly line. A task reassignment algorithm was applied to improve the initial solution by exchanging assembly tasks, which smooth postural load among workers, between workstations. A composite index of variation was used to measure the effectiveness of the task–workstation assignment solution. On the basis of clothes assembling, it was found that the task–workstation assignment solution with a minimum composite index of variation can be obtained with relatively equal weights in balance delay and postural load.

assembly line balancing   postural load smoothness   upper extremities disorders   RULA

1. INTRODUCTION

An assembly line balancing (ALB) problem is well-known in industry. An assembly line is specified by a finite set of tasks, processing time for each task and the precedence relationship which defines permissible ordering of tasks. The ALB problem involves assigning assembly tasks to workstations to optimize individual objectives without violating the precedence relationships. Important are ALB problems, cost reduction and an output rate increase by minimizing cycle time, lack of time or number of workstations. Because the ALB problem is a combinatorial optimization problem, the time needed to solve a problem increases progressively with the size of the problem, which makes large problems impossible to solve. Approximation algorithms were developed to obtain near-optimal solutions.

Heuristic procedures for solving the ALB problem are the most widely studied and discussed in the literature. Although the ALB problem has been studied for decades, new approximation algorithms are present in recent publications [1,

---

The authors are indebted to the Thailand Research Fund for providing financial support for this study through the research grant PHD/0138/2543.

Correspondence should be sent to Chorkaew Jaturanonda, Department of Production Engineering, King Mongkut's University of Technology Thonburi, Thung Krue, Bangkok, Thailand. E-mail: chorkaew.jat@kmutt.ac.th.

2, 3, 4, 5, 6, 7, 8, 9]. The metaheuristic procedures, e.g., genetic algorithms, are also efficient at finding solutions to bigger ALB problems [10, 11, 12, 13, 14]. Some ALB researchers developed mathematical models of dedicated and mixed models of ALB problems and applied optimization techniques like goal programming [15, 16] and branch-and-bound procedure [17, 18] to solve the problems.

According to Chow, ergonomics is an important issue which is not normally considered in assessing manual assembly tasks [19]. Cumulative trauma disorders, especially in the upper extremities, become essential problems in assembly industries because (a) workers while performing manually most assembly tasks maintain the same working posture for a prolonged time, (b) workers' body postures tend to be inappropriate especially when the assembly workstations are poorly designed or are nonadjustable, (c) assembly line workers have to produce a large quantity of products in a day and (d) workers use specific muscles repetitively. Ergonomists have studied various safety and health-related problems of assembly line workers and how the problems affect productivity and work efficiency. Aarås and Westgaard studied the postural load (PL) effects on musculoskeletal injuries of workers in an electromechanical assembly plant [20]. They found that an improvement in workers' posture reduced load on m. trapezius. Eklund evaluated the relationships between a number of ergonomics problems and product quality in car assembly line workers [21]. The findings showed that ergonomics problems had an influence on product quality. There were also studies on neck and upper extremity problems [22], carpal tunnel syndrome and other wrist/hand symptoms [23], and other work-related musculoskeletal symptoms [24] among car assembly line workers. The results showed that assembly tasks caused work-related disorders. A study on trailer assembly workers showed that if working methods changed, the load in the upper extremities and low back would also change [25]. Moreover, improvements in physical work environment help to alleviate musculoskeletal disorders among assembly line workers [26].

The most effective approach to preventing work-related disorders of the upper extremities among assembly line workers is an engineering approach involving modifying workstations and tools, and reducing musculoskeletal load. This approach is very often expensive and impractical. An administrative approach involving reducing exposure to ergonomics hazards (e.g., excessive physical workload, awkward work postures) through job rotation is also recommended. However, workers in an assembly line work system cannot change workstations. Assembly tasks need to be ergonomically assigned to workstations to reduce the workers' exposure to ergonomics hazards.

This study proposes a new heuristic procedure for the ALB problem, in which most assembly tasks are performed manually. The aim of this procedure was to find a task–workstation assignment solution which would minimize the balance delay of an assembly line and maximize the smoothness of PL among assembly line workers. A composite index of variation (*CV*) was developed as a weighted index to measure the balance delay of the assembly line and PL smoothness among workers. From a numerical ALB example, a task–workstation assignment solution is obtained with the proposed heuristic procedure. Various weight pairs given to the productivity and ergonomics issues were assumed. The change in *CV* was also investigated.

2. ALB PROBLEM WITH PL SMOOTHNESS

The ALB problem deals with two questions: (a) from a given number of workstations, how will assembly tasks be assigned to workstations to achieve the best ALB? and (b) from a given output rate, what is the minimum number of required workstations and how will assembly tasks be assigned to the workstations to achieve the best ALB? [27].

The precedence relationships must be strictly followed to assign assembly tasks to workstations. A widely acceptable measure of ALB is the balance delay, which is the amount of idle time on the line caused by an imperfect division of work between workstations. A task–workstation assignment solution with a minimum balance delay is an optimal solution to the ALB problem.

Assembly lines are manual, semiautomated or automated, depending on the level of workers' physical involvement. The distinction between the types of assembly lines is not clear and no literature has specified levels of workers' involvement. The assembly line described in this study is manual.

PL on the musculoskeletal system of assembly line workers can be assessed with rapid upper limb assessment (RULA) [28]. RULA was developed to investigate individual workers' exposure to risk factors associated with work-related upper extremities disorders [28]. The risk factors include working postures (based on upper arm, lower arm, wrist deviation, wrist twist, neck, trunk and legs), static muscle work and force exertion. RULA is a practical tool for evaluating jobs and tasks which expose workers to upper extremities disorders (neck, shoulder, hand, upper and lower arms). RULA grades individual body parts (the more awkward the body posture, the higher the RULA score), static muscle work and force exertion. RULA scores are combined into a grand score (1–7), which indicates one of four action levels. RULA prioritizes tasks to be investigated. Tasks with high scores impose excessive load on the musculoskeletal system and increase the risk of injury [28].

Generally, an assembly line worker has to perform several tasks. The sum of the grand scores from all tasks is called the workstation grand score (WGS). This score indicates the total PL that the worker has to endure. The smoothness of PL is indicated by how well WGSs are balanced. If the variation is small, the assignment of tasks to workstations is well balanced.

2.1. Quantitative Measures of Task–Workstation Assignment Solution

The main aim of this study was to find a task–workstation assignment solution which would help assembly line workers to achieve highest productivity. The solution could also help to distribute the tasks evenly among workstations so no worker would endure excessive PL. Subsections 2.1.–2.2. describe two quantitative measures of a task–workstation assignment solution based on the workstation processing time (WPT) and WGS. The value of *CV* allows concurrent consideration of both WPT and WGS.

Notations

CV	composite index of variation
M	number of tasks
N	number of workstations
t_i	processing time of task i
T_j	actual WPT of workstation j
$\bar{T}$	target (ideal) WPT
r_i	RULA grand score of task i
R_j	actual WGS of workstation j
$\bar{R}$	target (ideal) WGS
VR	normalized variance of WGS
VT	normalized variance of WPT
WR	weight in WGS
WT	weight in WPT

2.1.1. VT

The value of $\bar{T}$ is calculated by summing all task processing times and dividing it by N. It is an ideal WPT for every workstation in the assembly line to achieve a zero balance delay. The value of $\bar{T}$ is calculated with Equation 1:

$$\bar{T} = \frac{1}{N}\sum_{i=1}^{M} t_i. \tag{1}$$

After assigning assembly tasks to workstations, the value of T_j and a variance of WPT based on the task–workstation assignment solution (for N) can be determined. The value of VT is calculated with Equation 2:

$$VT = \frac{1}{\bar{T}}\frac{1}{N}\sum_{j=1}^{N}\left(T_j - \bar{T}\right)^2. \tag{2}$$

2.1.2. VR

The value of $\bar{R}$ is calculated with Equation 3:

$$\bar{R} = \frac{1}{N}\sum_{i=1}^{M} r_i. \tag{3}$$

The value of $\bar{R}$ is an ideal WGS for each workstation to achieve maximum PL smoothness.

After assigning assembly tasks to individual workstations, the value of R_j can be computed by summing r_i for all task assigned to a workstation. The value of *VR* is calculated with Equation 4:

$$VR = \frac{1}{\bar{R}} \frac{1}{N} \sum_{j=1}^{N} \left(R_j - \bar{R} \right)^2. \tag{4}$$

2.2. CV

The value of *CV* is a weighted average computed from *VT* and *VR*. Weights (0–1) must be assigned to WPT and WGS based on the decision-maker' view; the sum of the weights must equal 1. The value of *CV* is a quantitative measure for comparing different ALB problems with PL solutions. A solution with the lowest *CV* is the ALB problem with PL smoothness solution that yields the best task–workstation assignments for any given pair of weights. The value of *CV* is calculated with Equation 5:

$$CV = WT \cdot VT + WR \cdot VR. \tag{5}$$

The value of *CV* must equal 0 to obtain a completely balanced assembly line. The value of all WPTs must equal target WPT (i.e., achieve a zero balance delay) and all WGSs must equal target WGS (i.e., all workstations must have equal total PL). Because obtaining a completely balanced assembly line is difficult, obtaining a task–workstation assignment solution with a minimum *CV* is recommended.

3. HEURISTIC PROCEDURE

Although there are several heuristic algorithms for solving the ALB problem, they are intended to balance WPT only. This study proposes a heuristic procedure to find a task–workstation assignment solution that balances not only the processing times among workstations but also PL among workers. The procedure uses a classic Kilbridge and Wester's algorithm to generate an initial solution, and a task reassignment algorithm to improve the initial solution by reassigning tasks to new workstations to yield a minimum *CV* [27]. The number of workstations must be known in advance.

3.1. Kilbridge and Wester's Algorithm

The algorithm developed by Kilbridge and Wester is used because it is simple and yields a good ALB solution [27]. When generating the assignment solution, this algorithm considers WPT only. Figure 1 explains the computation steps of Kilbridge and Wester's algorithm.

VT, *VR*, and *CV* can be calculated from the resulting task–workstation assignment solution and the given weights.

3.2. Task Reassignment Algorithm

The initial task–workstation assignment solution is improved by either exchanging assembly tasks between two workstations or reassigning tasks from one workstation to the other without violating the given precedence relationships. A task reassignment algorithm selects pairs of assembly tasks to be exchanged or assembly tasks to be reassigned. If the *CV* of the new task–workstation assignment solution is reduced, an exchange of tasks or a reassignment of a task is recommended. Figure 2 shows the computation steps of the task reassignment algorithm.

4. NUMERICAL EXAMPLE

This study presents a heuristic procedure on the basis of Kilbridge and Wester's example of assembling clothes [27]. The operation is divided into 45 tasks. Jaturanonda and Nanthavanij showed a list of tasks involved in assembling clothes, task processing times and immediate predecessors [29]. It was assumed that the assembly line consisted of three workstations with one worker at each workstation. The weight of both WPT and WGS was 0.5.

4.1. Initial Solution From Kilbridge and Wester's Algorithm

A task–workstation assignment solution with a zero balance delay is achieved with Kilbridge and Wester's algorithm; WPT for each of the three workstations is 1.84 min. Investigating PL of the three workers at the three workstations involves graphic simulation of 45 assembly tasks and RULA evaluation of the worker's body postures and movements during hypothetical performance of those 45 tasks. Jaturanonda and Nanthavanij

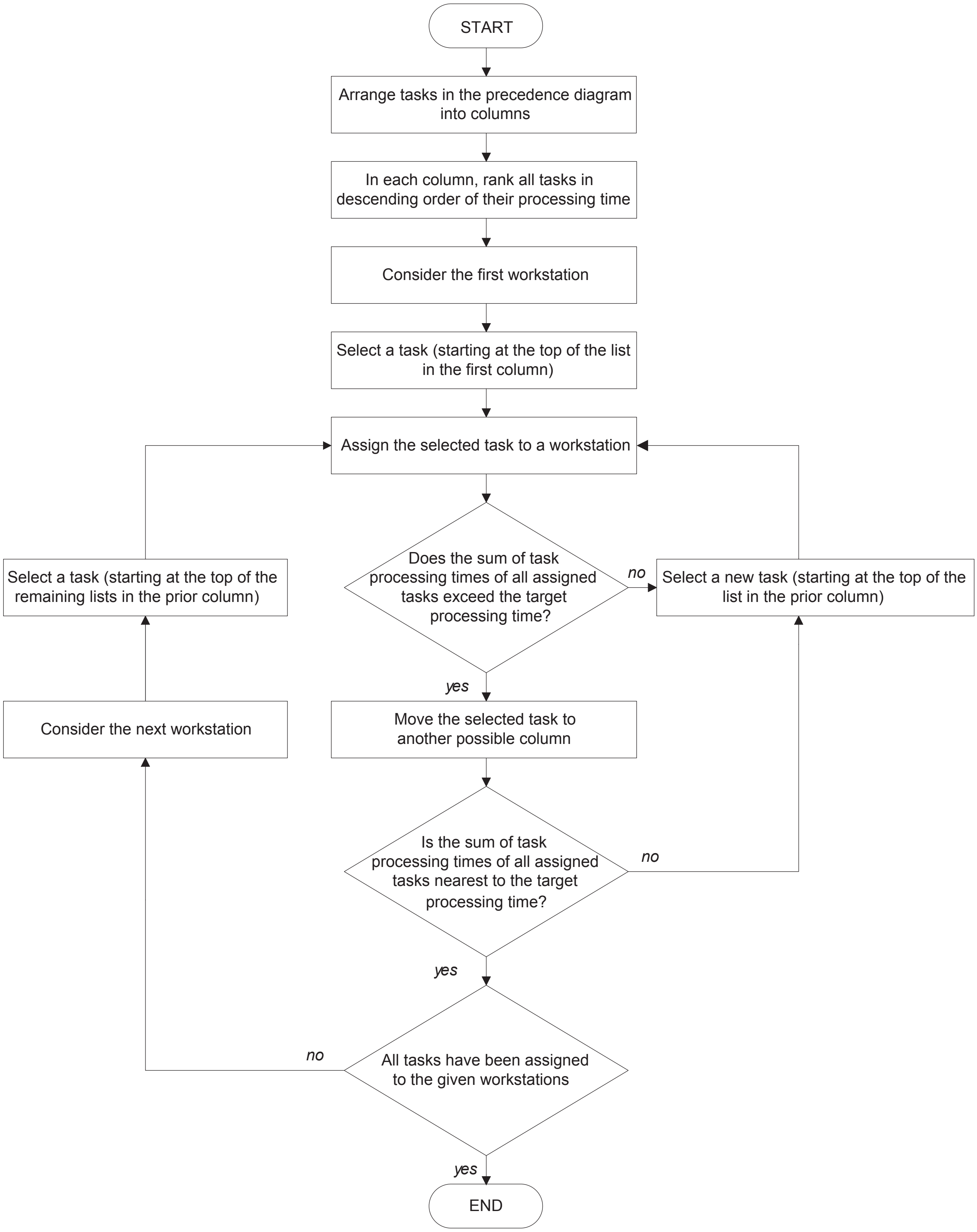

Figure 1. Kilbridge and Wester's algorithm [27].

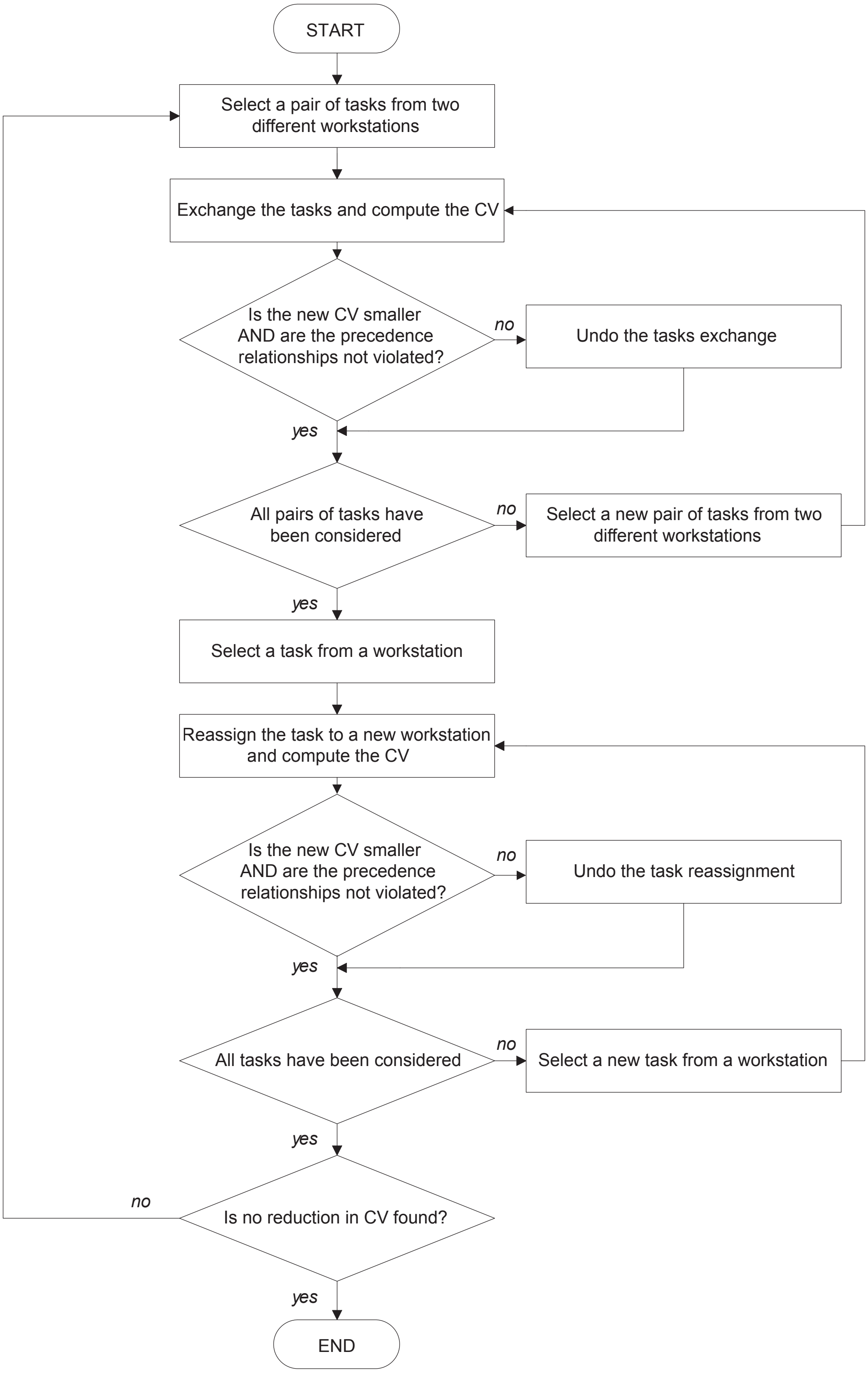

Figure 2. Task reassignment algorithm. *Notes.* CV = composite index of variation.

listed RULA scores and the grand scores of the 45 tasks [29]. The methods in section 2 of this study are applied to determine *VT*, *VR* and *CV* for the initial task–workstation assignment solution.

Table 1 shows the initial solution and its *CV*. Eighteen tasks are assigned to workstation 1, 12 to workstation 2 and 15 to workstation 3. The assembly line has a zero balance delay, $VT = 0$

and *CV* is influenced by no smoothness of PL caused by the imbalance of tasks assigned to the three assembly line workers.

4.2. Final Solution From Task Reassignment Algorithm

The initial solution is improved with a task reassignment algorithm described in section 3.2. Table 2 presents the final solution after task reassignments. Table 2 also presents the initial solution to make a comparison of the two solutions. The results show that the task reassignment algorithm can significantly improve the task–workstation assignment solution; *VR* is reduced from 2.3889 to 0.0139 but *VT* is still zero, final *CV* = 0.0069 (1.1944 in the initial solution). The number of assembly tasks assigned to the workstations are 16, 13, and 16 for workstation 1, 2 and 3, respectively.

On the basis of WPT, the final assignment solution from the heuristic procedure is as good as the solution from Kilbridge and Wester's algorithm. However, the lower *CV* indicates that the final assignment solution achieves better smoothness of PL; PL is distributed more evenly among the three workers.

4.3. Sensitivity of *CV* to Weights

Changes in *CV* when the weights given to WPT and to WGS are changed are investigated. Using the same numerical example, the weights of WPT vary from 0 to 1, with a step increment of 0.1 and the weights of WGS vary from 1 to 0. When the weight of WPT is zero, only the smoothness of PL among workers is important when assigning tasks to workstations.

The heuristic procedure is applied to each pair of weights to find the final task–workstation assignment solution with the smallest *CV*. Table 3 shows WPT for three workstations, *VR*, *VT* and *CV* for each pair of weights. When the weight of WGS increases, the balance delay also increases because of the increasing differences among the three WPTs. The value of *VT* is the highest for the ALB problem considering PL only. Using both weights in the middle range gives the best balance between the balance delay and PL in evaluating *CV*.

TABLE 1. Initial Task–Workstation Assignment Solution [27]

W 1		W 2		W 3	
Task	WPT (min)	Task	WPT (min)	Task	WPT (min)
1	0.09	16	0.19	9	0.20
2	0.09	17	0.12	10	0.20
3	0.10	18	0.04	25	0.26
4	0.10	19	0.03	26	0.06
5	0.17	20	0.07	28	0.24
6	0.17	21	0.55	33	0.15
7	0.13	22	0.14	34	0.07
8	0.13	23	0.27	35	0.07
11	0.10	24	0.29	36	0.09
12	0.11	27	0.05	38	0.03
13	0.06	29	0.04	40	0.04
14	0.22	30	0.05	41	0.21
15	0.11			42	0.12
31	0.07			44	0.05
32	0.04			45	0.05
37	0.04				
39	0.05				
43	0.06				
total	1.84		1.84		1.84

Notes. W = workstation; WPT = workstation processing time. Composite index of variation = 1.1944; normalized variance of workstation processing time = 0.0000; normalized variance of workstation grand score = 2.3889.

TABLE 2. Initial and Final Task–Workstation Assignment Solutions

Initial Solution[1]			Final Solution[2]		
W 1	W 2	W 3	W 1	W 2	W 3
1	16	9	1	3	9
2	17	10	2	4	22
3	18	25	7	5	23
4	19	26	8	6	26
5	20	28	11	10	28
6	21	33	12	18	33
7	22	34	13	19	34
8	23	35	14	20	35
11	24	36	15	21	36
12	27	38	16	25	38
13	29	40	17	27	39
14	30	41	24	37	40
15		42	29	43	41
31		44	30		42
32		45	31		44
37			32		45
39					
43					
WPT = 1.84	WPT = 1.84	WPT = 1.84	WPT = 1.84	WPT = 1.84	WPT = 1.84 min

Notes. 1 = Kilbridge and Wester's algorithm, composite index of variation = 1.1944, normalized variance of workstation processing time = 0.0000, normalized variance of workstation grand score = 2.3889; 2 = task reassignment algorithm, composite index of variation = 0.0069, normalized variance of workstation processing time = 0.0000, normalized variance of workstation grand score = 0.0139; W = workstation, WPT = workstation processing time (in minutes).

TABLE 3. Workstation Processing Time (WPT), Normalized Variances and Composite Index of Variation (*CV*) of Weight Pairs

Weight		WPT (min)			Normalized Variance		
WGS	WPT	W 1	W 2	W 3	WGS	WPT	*CV*
0.00	1.00	1.84	1.84	1.84	2.3889	0.0000	0.0000
0.10	0.90	1.80	1.86	1.86	1.0139	0.0435	0.1405
0.20	0.80	1.82	1.85	1.85	0.3889	0.0109	0.0865
0.30	0.70	1.83	1.84	1.85	0.0556	0.0036	0.0192
0.40	0.60	1.83	1.84	1.85	0.0556	0.0036	0.0244
0.50	0.50	1.84	1.84	1.84	0.0139	0.0000	0.0069
0.60	0.40	1.84	1.84	1.84	0.0139	0.0000	0.0083
0.70	0.30	1.81	1.85	1.86	0.0139	0.0254	0.0173
0.80	0.20	1.81	1.86	1.85	0.0139	0.0254	0.0162
0.90	0.10	1.84	1.86	1.82	0.0139	0.0145	0.0139
1.00	0.00	1.52	1.95	2.05	0.0139	2.8732	0.0139

Notes. WGS = workstation grand score, W = workstation.

Figure 3 shows changes in both normalized variances and in *CV* with respect to the weight pair. The task–workstation assignment solution that yields the smallest *CV* is the solution that gives equal weights to WPT and WGS. Nevertheless, using other weight pairs in the middle range also gives small *CV* and yields a good task–workstation assignment solution.

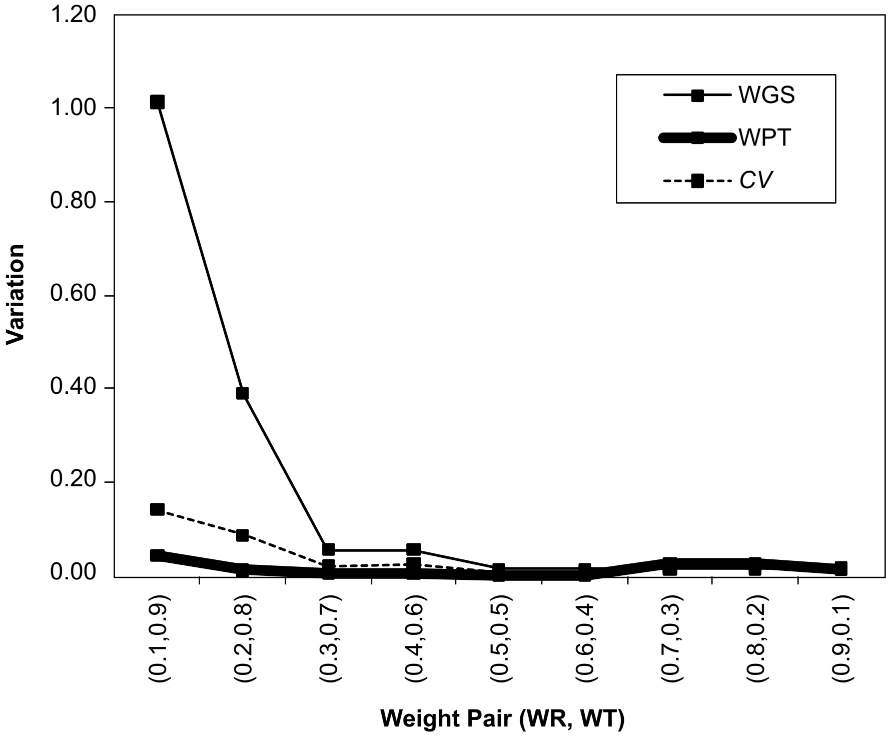

Figure 3. Normalized variances and composite index of variation (*CV*) versus weight pair. *Notes.* WGS = workstation grand score, WPT = workstation processing time, WR = weight given to WGS, WT = weight given to WPT.

The results of this study show that *CV* is insensitive to the weights given to the WPT and to WGS if their values are ~0.50. Moreover, the middle range of weight pairs also yields the best task–workstation assignment solution (with the smallest *CV*).

5. DISCUSSION

An example of clothes assembling was used to illustrate the heuristic procedure. Although the example is not from industry, it has the same properties (e.g., task times, precedence relationships) as many industrial jobs and it is not trivial. Kilbridge and Wester's algorithm for the assembly line with three workstations yields the task–workstation assignment solution that has a zero balance delay. Using the proposed heuristic procedure with equal weights given to WPT and WGS, the final task–workstation assignment solution is as good as Kilbridge and Wester's solution for the balance delay but better for the smoothness of PL. On the basis of the smallest *CV*, the best task–workstation assignment solution is obtained when the weights of WPT and WGS are equal. The value of *CV* is insensitive to the weight pairs form the middle range. Although the findings are based on the assembly line with three workstations, the assembly lines with different numbers of workstations will yield a similar results.

The task–workstation assignment solution, caused by its heuristic nature, might be only near-optimal. Nevertheless, its uniqueness in concurrently considering the productivity (through the balance delay) and ergonomics (through PL) issues when assigning assembly tasks to workstations is expected to outweigh the above argument. The use of an approximation algorithm makes it a good analysis tool especially for large ALB problems with PL smoothness.

The proposed heuristic procedure is developed specifically for a manual assembly system. It is difficult to define whether the assembly line is a manual system and to decide whether the heuristic procedure will be applicable; however, the degree of physical involvement and the awkwardness of the work posture could be used to justify using the heuristic procedure. The heuristic procedure should be very applicable to the assembly line where workers must routinely perform physical tasks or they must repetitively work with awkward body postures. In assessing the risk for cumulative trauma disorders, RULA only emphasizes the awkwardness of body postures and movements, not their duration. The heuristic procedure can be used for manual assembly lines with well-designed workstations and tools or those with the tasks which are not physically intensive. The resulting task–workstation assignment solution should not significantly differ from the solution obtained when considering WPT.

There are several recommendations which will enhance the effectiveness of the heuristic procedure and provide applicable results. PL is assessed with RULA; RULA is applicable to the assembly line in which workers sit during work but it can also be used to evaluate assembly line in which workers stand. Workers should stand or they should not do excessive movements because RULA is a snapshot analysis of work posture. Light manual tasks should be performed at the assembly line. To select the appropriate weights assigned to *VT* and *VR*, several weight pairs should be evaluated to determine the pair that yields the smallest *CV*.

6. CONCLUSION

This study describes the heuristic procedure for the ALB problem with PL smoothness. The procedure balances WPT to minimize the balance delay and PL imposed on the musculoskeletal system of assembly line workers. RULA evaluates postures of seven body parts, static muscle work and force exertion during assembly tasks. The sum of the RULA grand scores from all tasks at the workstation implicitly indicates the total PL that the worker must endure. The value of *CV* reflects the variation among WPT and the variation among WGS.

The solution procedure consists of two stages. Firstly, an initial task–workstation assignment solution is generated with Kilbridge and Wester's algorithm, which considers WPT only. Next, the initial solution is improved by swapping certain pairs of tasks from different workstations or reassigning certain tasks to new workstations if such action will decrease *CV*. The task reassignment is repeated until no further improvements can be made. The resulting task–workstation assignment solution is the solution with the smallest *CV*.

REFERENCES

1. Shin D. An efficient heuristic for solving stochastic assembly line balancing problems. Computers and Industrial Engineering. 1990;18(3):285–95.
2. Nourie FJ, Venta ER. Finding optimal line balances with OptPack. Operation Research Letters. 1991;10(3):165–71.
3. Park K, Park S, Kim W. A heuristic for an assembly line balancing problem with incompatibility, range, and partial precedence constraints. Computers and Industrial Engineering. 1997;32(2):321–32.
4. McMullen PR, Frazier GV. A heuristic for solving mixed-model line balancing problems with stochastic task durations and parallel stations. International Journal of Production Economics. 1997;51(3):177–90.
5. Kim YJ, Kim YK, Cho Y. A heuristic-based genetic algorithm for workload smoothing in assembly lines. Computers and Operations Research. 1998;25(2):99–111.
6. Sarin SC, Erel E, Dar-El EM. A methodology for solving single-model, stochastic assembly line balancing problems. Omega. 1999;27(5): 525–35.
7. Amen M. Heuristic methods for cost-oriented assembly line balancing: a comparison on solution quality and computing time. International Journal of Production Economics. 2001;69(3):255–64.
8. Jin M, Wu SD. A new heuristic method for mixed model assembly line balancing problem. Computers and Industrial Engineering. 2003;44(1):159–69.
9. Fleszar K, Hindi KS. An enumerative heuristic and reduction methods for the assembly line balancing problem. Euro J Oper Res. 2003;145(3):606–20.
10. Rubinovitz J, Levitin G. Genetic algorithm for assembly line balancing. International

Journal of Production Economics. 1995; 41(1):343–54.

11. Gen M, Tsujimura Y, Li Y. Fuzzy assembly line balancing using genetic algorithms. Computers and Industrial Engineering. 1996;31(3–4):631–34.

12. Kim YK, Kim YJ, Kim Y. Genetic algorithms for assembly line balancing with various objectives. Computers and Industrial Engineering. 1996;30(3):397–409.

13. Ponnambalam SG, Aravindan P, Mogileeswar Naidu G. A multi-objective genetic algorithm for solving assembly line balancing problem. Int J Adv Manuf Technol. 2000;16(5):341–52.

14. Chen RS, Lu KY, Yu SC. A hybrid genetic algorithm approach on multi-objective of assembly planning problem. Eng App Artif Intelligence. 2002;15(5):447–57.

15. Deckro RF, Rangachari S. A goal approach to assembly line balancing. Computer and Operations Research. 1990;17(5):509–21.

16. Gokcen H, Erel E. A goal programming approach to mixed-model assembly line balancing problem. International Journal of Production Economics. 1997;48(2):177–85.

17. Berger I, Bourjolly JM, Laporte G. Branch-and-bound algorithms for the multi-product assembly line balancing problem. Euro J Oper Res. 1992;58(2):215–22.

18. Klein R, Scholl A. Maximizing the production rate in simple assembly line balancing: a branch and bound procedure. Euro J Oper Res. 1996;91(2):367–85.

19. Chow WM. Assembly line design: methodology and applications. New York, NY, USA: Dekker; 1990.

20. Aarås A, Westgaard RH. Further studies of postural load and musculo-skeletal injuries of workers at an electro-mechanical assembly plant. Appl Ergon. 1987;18(3):211–9.

21. Eklund JAE. Relationships between ergonomics and quality in assembly work. Appl Ergon. 1995;26(1):15–20.

22. Zetterberg C, Forsberg A, Hansson E, Johansson H, Nielsen P, Danielsson B, et al. Neck and upper extremity problems in car assembly workers. A comparison of subjective complaints, work satisfaction, physical examination and gender. Int J Ind Ergon. 1997;19(4):277–89.

23. Zetterberg C, Öfverholm T. Carpal tunnel syndrome and other wrist/hand symptoms and signs in male and female car assembly workers. Int J Ind Ergon. 1999;23(3): 193–204.

24. Engström T, Hanse JJ, Kadefors R. Musculoskeletal symptoms due to technical preconditions in long cycle time work in an automobile assembly plant: a study of prevalence and relation to psychosocial factors and physical exposure. Appl Ergon. 1999;30(5):443–53.

25. Häkkänen M, Viikari-Juntura E, Takala EP. Effects of changes in work methods on musculoskeletal load: an intervention study in the trailer assembly. Appl Ergon. 1997; 28(2):99–108.

26. Fredriksson K, Bildt C, Hägg G, Kilbom Å. The impact on musculoskeletal disorders of changing physical and psychosocial work environment conditions in the automobile industry. Int J Ind Ergon. 2001;28(1):31–45.

27. Kilbridge M, Wester L. A heuristic method of assembly line balancing. Journal of Industrial Engineering. 1961;12(4):292–8.

28. McAtamney L, Nigel Corlett E. RULA: a survey method for the investigation of work-related upper limb disorders. Appl Ergon. 1993;24(2):91–9.

29. Jaturanonda C, Nanthavanij S. Heuristic procedure for two-criterion assembly line balancing problem. Industrial Engineering and Management Systems. 2006;5(2). Retrieved September 20, 2013, from: http://www.iemsjl.org/index.php?mid=ContentofPresentissue&category=2930&document_srl=4016.