Expert System for Mixed-Model Assembly Line Balancing

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Abstract

A heuristic for solving the mixed-model assembly line balancing problem using the CLIPS expert system is presented. The system utilizes an experience-based line balancing procedure, which is a modified version of an existing published line balancing heuristic, to construct facts and rules without deteriorating the balancing precedence constraints and performance. The system determines the set of assembly tasks at each workstation necessary to achieve the objective of minimizing the amount of idle time at each workstation.

Keywords: Heuristic, CLIPS expert system, mixed-model line balancing, computer assembly tasks, idle time (slack time).

1. Introduction

The assembly line balancing problem can be explained as the requirement to assign task elements according to precedence relations and some other constraints (i.e, the compatibility between a station and some tasks) to each workstation on the production line in order to achieve specific objectives, such as maximizing the production rate and minimizing the number of workstations, cycle time, and slack time. Furthermore, line balancing will reduce the differences between assigned workloads so that one operator is not very busy while other operators are idle. This situation wastes valuable human resources [1]. According to Erel and Sarin [2], the assembly line balancing procedure was first applied in 1913 by Henry Ford and, since then, there have been many different types of published heuristic procedures. It has known that the assembly line balancing problem is a NP-hard problem in which the computational time to obtain the optimal solution increase exponentially as the problem size increases [3]. For this reason, heuristic methods are used to obtain a satisfactory solution because it takes too much computation time to determine the optimal result. In the recent production environment, the requirement to provide a production system that quickly responds to frequent changing demands in highly competitive markets is very desirable. The traditional line balancing approach is no longer suitable for the new generation of production systems. Meanwhile, in practice, many companies are still balancing their assembly lines by either manual operation or historical precedent without utilizing the published procedures.

2. Heuristic Methods and Expert System Approach

2.1 Heuristic Methods

Line balancing involves assigning the task elements to achieve multiple objectives. There are several models that are able to use when considering different objective functions. The first type of model is a mathematic model combined with a heuristic method. For examples, Hoffmann [4] combined a branch and bound algorithm with a heuristic method to approach the optimal solution, and Erel and Gokcen [5] modified the Patterson et al. algorithm with a binary goal-programming model to achieve the satisfactory results when facing conflicting goals. The second type of model is a heuristic search that is based on the existing solution. Malakooti [6] use existing heuristic balancing approaches to generate a set of efficient alternatives to minimize the buffer size in the case of multiple criteria. Sonekar et al. [7] proposed a multiple criteria decision-making (MCDM) approach to minimize the number of subassemblies. This system was able to generate an entire set of efficient alternatives and used an interactive paired comparison of alternatives to solve the problem. The third type of model is a heuristic search that concentrates on less processing time. For instance, Boctor [3] proposed a heuristic that utilized a single-pass and composite method consisting of general assignment with priority ordering. The composite method is a four-rule heuristic method for line balancing to seek the minimum number of workstations for a given cycle time. The fourth type of model is used to solve multi-objective problems. Kabir and Tabucanon [8] used an analytic hierarchy process and simulation (known as the Ignall algorithm) to determine the number of workstations in a multi-attribute problem. One common feature of all these models is to use both an algorithm and heuristic procedures to produce satisfactory solutions, which are not necessarily the optimal solution.

From the practical viewpoint, the heuristic method should use software to select the best solution. As an example reported by Enmer et al. [9], a model was introduced to balance an industrial truck engine assembly line. The heuristic generated all the feasible alternative sets of tasks for a single station, selecting the one with the least slack and then moved to the next station. Unfortunately, due to the simplified assumptions found in most heuristic methods and complexity of the real system, many line balancing tasks were still performed manually. This problem leads to another research direction, the intelligent system. In the intelligent line balancing system approaches, the intelligent component is implemented by using an expert system. Roy and Allchurch [10] proposed a Prolog expert system to perform mixed-model assembly line balancing. The system utilized industrial engineering knowledge and a practical line balancing method from the motor industry to construct the model. Oh [1] presented an expert line balancing system (ELBS). The ELBS applied a heuristic method and computerized into expert system shell that performs as an expert in an interactive mode. This system produced the number of substations in each major operational station, system cycle time, total number of stations in the system, total number of hours required, and overall efficiency. Kumar and Malakooti [11] reported an expert system model, which was constructed in C programming. The purpose of this model is to assist the practitioner in making decisions when there are many conflicting objectives. One remarkable approach used in intelligent line balancing methods is to incorporate the precedence network of the product to increase the decision-making capability for the line balancing procedures. Arinze and Partori [12] were the first to report a system that was able to produce the precedence network from a knowledge-based system to perform all the job allocations. Sudhir and Rajagopalan [13] also presented a framebased model, the ANGEL prototype system, to generate the precedence network through an artificial intelligence approach for assembly line balancing.

2.2 Expert System Approach

The expert system approach is one of the artificial intelligence (AI) methods, which takes the essential knowledge from a problem domain and utilizes various inference strategies to solve problems in that domain. The system shifts from the procedural to declarative representation with a separation of the knowledge representation from the processing of the knowledge [13]. Expert systems are regularly applied to the ill-structured problem in which the problem can be defined but the knowledge and information needed are complicated, poorly defined, and qualitative. In order to develop an expert system, the knowledge engineer and expert in a specific field, known as the knowledge domain expert, must assist each other. The knowledge engineer must be familiar with the software being used in order to construct the knowledge-base through extracting the essential information from the domain expert. The advantages of the expert system, such as consistent performance, stable reliability, and fast response, provide the capability to solve the assembly line balancing problems. Especially for the mixed-model assembly line balancing problem, it is vital to have fast response and stable reliability. In this research, an expert system programming language, CLIPS, has been chosen to implement the software system. CLIPS, which represents CLanguage Integrated Production System, is an expert system programming language developed by the NASA/ Johnson Space Center with the specific goals of providing high portability, low cost, and easy integration with external systems. The advantage to using CLIPS is that it provides the support for rule-based, object-oriented, and procedural programming [14].

3. Problem Definition and Objectives

Many complex assembly lines such as those found in the automotive to computer assembly industries, are balanced by manual calculations. This operation is very time-consuming and is very inflexible to responses caused by dynamic changes in market demands. A better way to perform the balancing task is to use the experience-based heuristic procedures in order to achieve a productive resource allocation. Many practitioners have problems with the complexity of the proposed methodologies, which are more difficult to apply than just using their skill and judgment. Consequently, the traditional methods, based on the manager's experience and intuition, are widely implemented in many assembly industries. Applying the expert system becomes one of the alternative ways to improve the line-balancing task. Through this approach, many complex algorithms can be selectively incorporated within the heuristic approach, which applies an experience-based solution. This approach can replace the manual calculations and incorporate the heuristic or mathematic procedures while still keeping the flexibility.

This study introduces a new application of the mixed-model assembly line balancing concept by using an expert system programming language, CLIPS. The main purpose of this study is to design a system, which is a mixedmodel assembly line balancing system, that includes a CLIPS expert system to smooth the daily production control of a personal computer (PC) assembly line. This system, therefore, demonstrates that tedious and complex tasks can be replaced by an expert system using a published heuristic algorithm to obtain the time saving and satisfactory results. In this case study, the PC assemble line is the final assembly line, which collects many parts from preceding processes. The production line consists of many workstations in which some are part of the fixed facility layout and some can be changed. On the production line, there are a variety of PC models assembled with mixed orders. One station is capable of assembling many kinds of models and operators can perform overlapping tasks. The objectives of the system are as follows :

- To increase the production productivity and stability
- To create intelligent decision-making capability and control of the production line
- To replace the supervisor's job with an intelligent system
- To have a more flexible production control system (real-time response)
- To create a line balancing technique for mixed-model assembly

4. A Heuristic Method with an Expert System

This study extends the applications found in the literature. In this study, the concepts of the mixed-model assembly line balancing and the use of an intelligent system with an expert system are proposed to generate a new integrated production control approach to assembly line balancing for PC production. In the function of line balancing, the traditional line balancing concept is replaced by the weighted average balancing concept with an improved ranked positional weight heuristic [15]. The expert system logic is coded with the CLIPS programming language. The operation has four steps, which are system initialization, new single-model line balancing, mixed-model line balancing, and daily control line balancing.

The system initialization includes (step 1) initialing the tasks, stations of the facility, and compatibility among tasks and workstations. The parameters include cycle time (CT), workstation number (Sj), takt time (Tk), set of tasks in workstation (C), set of unassigned jobs (MU), slack time (SL), set of tasks before the assignment is completed (IC), set of previous jobs that must be completed before task i (PRi), and other related information. When the system is started from beginning with zero product models, the new single-model line balancing, Step 2, is required. This step is modified from Mansoor's heuristic method [15] and the procedure is shown in Figure 1. This step generates the line balancing assignments for a single product model. When the user tries to balance the product line for a mixedmodel (more than two product models) scenario, step 3 will be performed. Step 3 is also modified from Mansoor's heuristic which adds the new product model into the existing task assignments for the product line and continues the modification until the constrains have been satisfied. The procedure is shown in Figure 2. Step 4, daily control line balancing, is used to handle the abnormal situations in the assembly line, which performs like an online supervisor. This step contains a collection of short and simple balancing modification procedures that emphasis various abnormal situations. The procedures will be effective when an abnormal situation occurs in the assembly line, resulting in a change of total actual cycle time of the workstation and changing the balancing ratio.

5. Demonstration Example

In order to demonstrate the system, two computer models are randomly selected. The required assembly tasks and time for each task are shown in Table 1 and 2, which was the result of time and motion studies. It is assumed the product line will produce with 500 time-units of the first model when a single model is required and the product quantities will change to 250 time-units for the new model and 250 time-units for the old model during mixed model production. The results of initial balancing (single model) and mixed-model balancing (two models) are shown in Table 3 and 4. For the single model assignment, the overall effectiveness of line balancing is 64.24% with 80.39% for balancing and workstation effectiveness, and the production effectiveness is 99.40%, respectively. In addition, the overall effectiveness for mixed model balancing is 54.80% with 65.40% and 83.78% for balancing and workstation effectiveness, and the production effectiveness is 100%, respectively.

The results obtained for the single-model line balancing utilized the initialization step and new-single model line balancing step. The results for the mixed-model line balancing applied three steps, initialization, new single-model line balancing, and mixed model line balancing. In this example, the results from the mixed-model balancing had no effect on the first model's task assignments but added nine new workstations to the second model's task assignments. Also, because the demonstration was not done online and no interference was presented. Step 4 was inactive in this example.

6. Conclusion

In current industrial operations, assembly line balancing techniques are most implemented by manual procedures with an experience-based approach due to the complexity of published procedures. This study aims to diminish this problem by introducing an expert line balancing system approach to minimize the slack time (balancing) at each workstation. The system is able to generate the desired sets of tasks at each workstation in relatively short time compared to manual calculations. Due to the nature of the algorithm applied, the system cannot guarantee an optimal solution. This expert system performs the initial balancing using an existing heuristic, which is a ranked positional weight heuristic [15] (single-model balancing), and achieves the mixed-model balancing using modified Mansoor's heuristic, with all the procedures implemented by a CLIPS expert system. Furthermore, the system has the ability to smooth the daily activity when abnormalities occur. Therefore, this expert system can adjust the assembly operation to maintain a balanced performance.

This study utilized an expert system to implement the heuristic algorithm and part of the procedure was developed from a mathematic model. This combination allowed the complex procedure to be integrated with the experiencebased decision process that releases the repetitive manual calculation tasks from product-line-supervisor. This system can be continually developed by improving the heuristic for initial balancing and mixed-model balancing, and by adding a rebalancing procedure for different abnormal scenarios. This type of system can assist not only computer assembly companies but also other companies that want to minimize production lead-time in order to better respond to rapid changes in market demands. By combining the experience of many engineers and the results of academic research into a single platform, the production tasks, such as assembly operations, will become more flexible, which leads to the improvement of overall productivity.

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Assembly tarks for A-model

No.	Work elements	time (0.001 minute)	PW_j
1	load inner case	87	**25372**
2	assembly mother broad	182	**25285**
3	screw mother broad	2 x 250	**25103**
4	assembly lever	2 x 500	**2324**
5	assembly speaker	500	**3924**
6	screw speaker case	7 x 300	**3424**
7	assembly RAM	8 x 350	**4624**
8	insert cable	500	**1824**
9	insert cards	4 x 500	**10140**
10	assembly drive A	480	**10195**
11	screw drive A	3 x 325	**9715**
12	assembly drive B	8 x 200	**8740**
13	assembly switch	2 x 500	**7140**
14	subassembly hard drive	123	**7179**
15	screw hard drive	6 x 200	**7056**
16	assembly hard drive to case	572	**5856**
17	insert main cable	700	**2024**
18	insert PW cable	2 x 148	**2840**
19	assembly PW	100	**2544**
20	screw PW	4 x 200	**2124**
21	insert switch cable	220	**1544**
22	insert miner cable	600	**1924**
23	assembly upper case	524	**1324**
24	screw upper case	4 x 200	**800**

Table1. Assembly tasks of A-model

Assembly tarks for B-model

No.	Work elements	time (0.001 minute)	PW_j
1	load upper case	89	**21813**
2	assembly mother broad	258	**21724**
3	screw mother broad	6 x 195	**21466**
4	insert fan cable	191	**1983**
5	insert RAM	8 x 123	**2776**
6	assembly cable	311	**2103**
7	assembly network card	411	**4646**
8	assembly I/0	567	**4235**
9	assembly VDO card	296	**3668**
10	assembly control card	267	**3372**
11	assembly drive A	119	**6156**
12	screw drive A	2 x 180	**6037**
13	assembly drive B	72	**5677**
14	screw drive B	2 x 180	**5605**
15	assembly hard drive	137	**5742**
16	screw hard drive	2 x 180	**5605**
17	insert frontal case	685	**2812**
18	insert cable from frontal case to broad	335	**2127**
19	insert cable from disk drives to broad	400	**2192**
20	assembly PW	118	**3105**
21	screw PW	4 x 194	**2987**
22	insert flat cable	64	**1856**
23	insert PW cable	731	**2523**
24	insert flat cable	400	**2192**
25	assembly outer case	227	**1792**
26	screw outer case	5 x 313	**1565**

Table2. Assembly tasks of B-model

No.	Station	Job assignment
1	*1*	1,2
2	*2*	3,11
3	*2.1*	3,11
4	*2.2*	3,11
5	*3*	12,15
6	*4*	13,14
7	*5*	16
8	*6*	7
9	*7*	8,9
10	*7.1*	8,9
11	*8*	10,20
12	*9*	21
13	*9.1*	21
14	*10*	17
15	*10.1*	17
16	*11*	5
17	*11.1*	5
18	*12*	23
19	*12.1*	23
20	*13*	19
21	*14*	24
22	*15*	18
23	*16*	6
24	*17*	4,22,25
25	*18*	26
26	*18.1*	26
27	*18.2*	26
28	*18.3*	26

Table3. Assignment of B-model

No.	Station	Job assignment B-model	Job assignment A-model
1	*1*	**1,2**	**1,2**
2	*2*	**3,11**	**3**
3	*2.1*	**3,11**	**10**
4	*2.2*	**3,11**	**14,15**
5	*2.3*		**14,16**
6	*3*	**12,15**	**11,16**
7	*3.1*		**11,17**
8	*3.2*		**11,18**
9	*4*	**13,14**	**12**
10	*4.1*		**12**
11	*4.2*		**12**
12	*5*	**16**	**18**
13	*6*	**7**	**9**
14	*7*	**8,9**	**10**
15	*7.1*	**8,9**	**11**
16	*8*	**10,20**	**12**
17	*9*	**21**	**19,20**
18	*9.1*	**21**	**20**
19	*10*	**17**	**4**
20	*10.1*	**17**	**5**
21	*11*		**6**
22	*11.1*		**6**
23	*12*	**5**	**7**
24	*12.1*		**7**
25	*12.2*	**5**	**7**
26	*12.3*		**7**
27	*13*	**23**	**17**
28	*13.1*	**23**	**17**
29	*14*	**19**	**21**
30	*15*	**24**	**22**
31	*16*	**18**	**22**
32	*17*	**6**	**8**
33	*18*	**4,22,25**	**23**
34	*19*	**26**	**23**
35	*19.1*	**26**	**24**
36	*19.2*	**26**	**24**
37	*19.3*	**26**	

Table4. Assignment of A and B-model

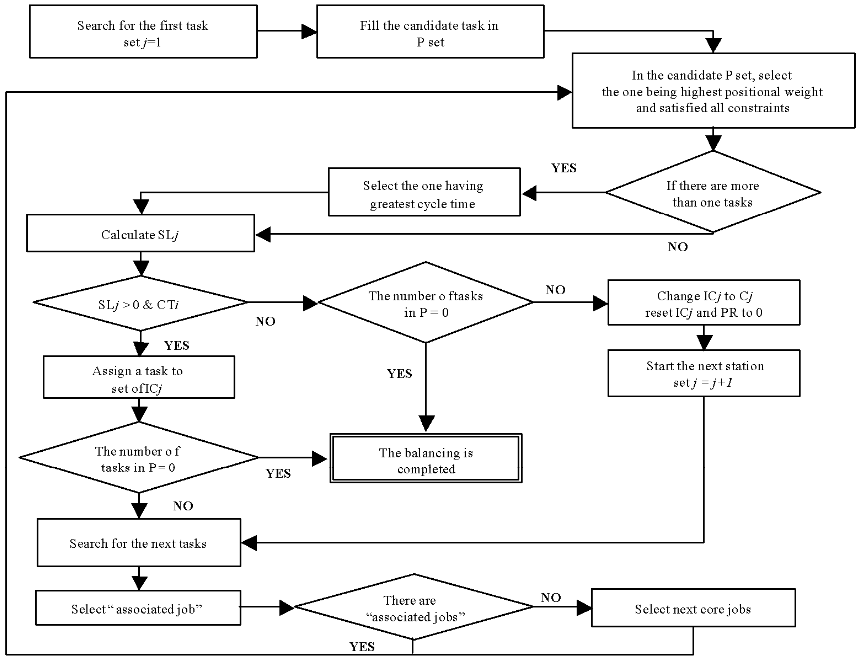

Figure 1. Single model line balancing procedure

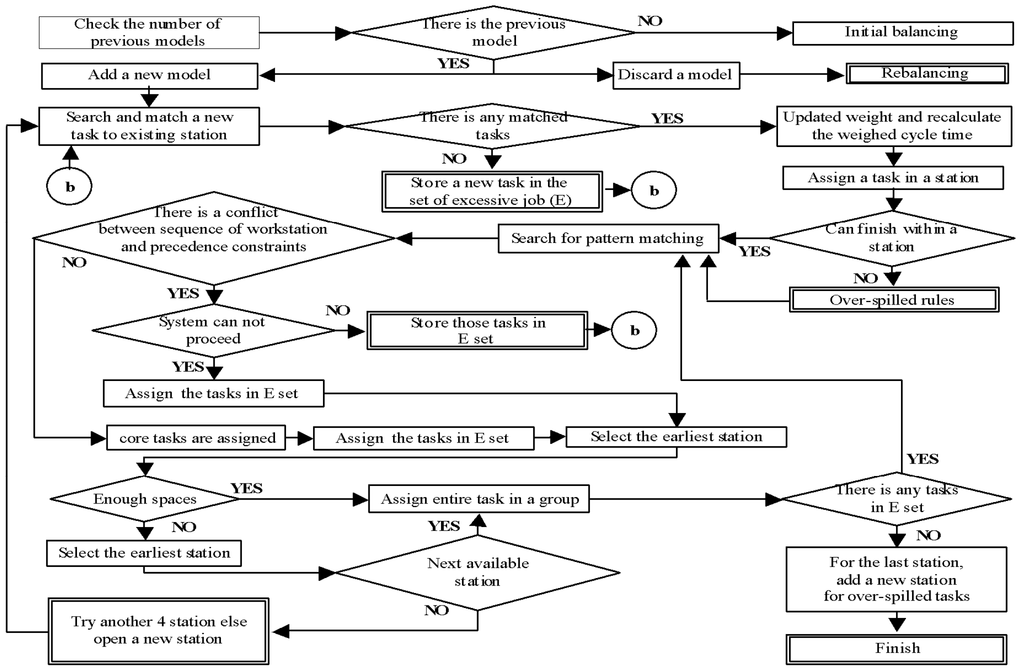

Figure 2. Mixed model line balancing procedure