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PRODUCTION CAPACITY OPTIMIZATION OF AN HVAC ASSEMBLY LINE IN AN AUTOMATIVE COMPANY

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ABSTRACT

The objective of this study is to present a tool for line balancing and cycle time optimization for an HVAC system assembly line in an automotive company. To increase the production capacity of the HVAC system assembly line, we aim to minimize the cycle time of two mainly produced products, automatic and manual ACs. By doing that, the efficiency of the HVAC system assembly line is increased and the workloads of stations are balanced.

We implement an integer programming model using a commercial software package and are able to obtain the optimal solution in less than a few minutes usually. Furthermore, we analyze different scenarios by making some changes on the line. As a result cycle time is reduced about 10%. A remarkable increase in the number of products is provided by this reduction in cycle time without any investment required by the company.

Keywords: Assembly line balancing, cycle time reduction, mathematical programming

BİR OTOMOTİV FİRMASI İKLİMLENDİRME SİSTEMİ MONTAJ HATTINDA ÜRETİM KAPASİTESİ OPTİMİZASYONU

ÖZ

Bu çalışmanın amacı bir otomotiv firmasındaki iklimlendirme sistemleri montaj hattı için hat dengeleme ve çevrim süresi optimizasyonu için bir aracın geliştirilmesidir. İklimlendirme sistemi hattının üretim kapasitesini arttırmak için otomatik ve manuel klimaların çevrim sürelerinin minimize edilmesi amaçlanmıştır. Böylelikle iklimlendirme sistemi hattının etkinliği artarak, istasyonların iş yükleri dengelenmiş olacaktır.

Ticari bir yazılım kullanılarak oluşturulan tamsayılı programlama modeliyle optimal çözümler genel olarak birkaç dakikadan daha kısa bir sürede elde edilebildiği görülmektedir. Buna ek olarak, hat üzerinde bazı değişikliklerin öngörüldüğü farklı senaryolar incelenmiştir. Sonuç olarak, çevrim süresinin yaklaşık olarak %10 azaldığı görülmüştür. Bu şekilde, firma tarafından herhangi bir yatırım gerektirmeyen önemli bir üretim artışı sağlanmaktadır.

Anahtar Kelimeler: Montaj hattı dengeleme, çevrim süresi azaltma, matematiksel programlama

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1. INTRODUCTION

Assembly is combining parts in a specific order in a system. Assembly process begins with completely separated segments and ends with combining all those parts in to a system (Sinanoglu and Borklu, 2002). An assembly line is a flow-oriented production system where workpieces visit stations and combine in sequence and a specific order. (Sinanoglu and Borklu, 2002). "Assembly Line Balancing" is assigning operations to assembly stations considering; minimizing the lost time during production (Tanyas and Baskak, 1996). The utilization ratio of each of the work station on the assembly line (total operating time) should maximize operator efficiency or minimize the risk of a line stoppage (Xiaobo et al., 1999). Assembly-lines are used to produce a variety of products in many different industries.

Assembly line balancing problems are examined as single model, mixed-model and multi model assembly lines. Two types of optimization problem arise in line balancing problems. In the first type, given the number, time and priorities of the operations and the cycle time, the purpose is to find the minimum number of stations. Type 1 is usually used at new assembly lines. In the second type of problems, the number of stations and operations are constants and the aim is minimizing the cycle time (Ajenblit, 1998). Another classification is as follows:

- Single Model Assembly Lines: Single model assembly lines are mass production of one product. Equal amount of same procedures are made at each station continuously. This type of assembly lines is the least complex compared to other assembly lines.
- Mixed-Model Assembly Lines: Several models of a product are produced on the same assembly line. Production processes of model are nearly the same however, some of the features, size, color, materials, operations and operation time, the priority relationships differ. The first study on the mixed-model assembly line balancing is made by Thompoulos (1967-1970). Later on, different balancing methods have been used in many studies.
- Multi-Model Assembly Lines: Few products are produced at one or several assembly line. Due to significant differences in the production processes, it is necessary to rearrange equipment in the assembly line when produced product changes. Efficient time is reduced because of preparation times at multi-model assembly lines. As a result, in order to minimize lost time at preparation.

2. PROBLEM DEFINITION

In order to observe the current situation and identify bottlenecks, a simulation model is created using Arena. Input data for the simulation model are collected via time study analyses, and probability distributions are obtained. According to the results of the simulation model which represent the current situation, there is a workload imbalance between stations as seen in Table 1. The utilization ratio differences between stations cause downtimes for some stations and increase the cycle time of the line.

Activities that reduce the speed of the line are observed, and as a result of these, eight scenarios are designed for both products (automatic and manual HVACs) as seen in Table 2 and Table 3, respectively. While calculating the costs of the scenarios, the costs that will arise as a result of modifications are investigated. For instance, the cost of an extra table when some of the operations are taken out of the assembly line or the cost of rearrangements due to changing the sequence of operations is ignored since such arrangements will be obtained from firm's resources so that they will not create an additional cost.

3. IMPLEMENTATION AND RESULTS

The mathematical model derived from the literature is implemented using Mathematical Programming Language (MPL). An MS Excel interface is created to provide a user-friendly decision support system which presents optimal job assignments and cycle time without interfering MPL, and therefore, the optimal solutions for all scenarios can be reached easily by changing the required data in Excel sheets. The utilizations of the stations are also shown with an automatically created graph in order for the user to check the utilizations of the stations visually.

Table 1. Operator Utilizations

Operator	Utilization
1	0.1129
2	0.1791
3	0.1658
4	0.1592
5	0.1509
6	0.1264

Table 2. Scenario Descriptions for the Automatic HVAC Unit

Scenario	Number of Operators (on-line)	Number of Operators (off-line)	Number of Stations	Operations (off-line)	Cycle Time
Current	6	-	5	-	90.88
S0	6	-	5	-	80.07
S1	6	1	5	10, 25, 26, 27	75.24
S2	7	-	6	-	68.83
S3	7	1	6	10, 25, 26, 27	63.94
S4	6	1	5	10	78.19
S5	6	1	5	25, 26, 27	75.93
S6	7	1	6	10	66.49
S7	7	1	6	25, 26, 27	63.95

Table 3. Scenario Descriptions for the Manual HVAC Unit

Scenario	Number of Operators (on-line)	Number of Operators (off-line)	Number of Stations	Operations (off-line)	Cycle Time
Current	6	-	5	-	91,10
S0	6	-	5	-	83,31
S1	6	1	5	10, 26, 27, 28	78,10
S2	7	-	6	-	69,30
S3	7	1	6	10, 26, 27, 28	66,40
S4	6	1	5	10	82,01
S5	6	1	5	26, 27, 28	80,10
S6	7	1	6	10	69,30
S7	7	1	6	26, 27, 28	68,80

Solution of the problem needs to fulfill the following conditions:

- Each operation must be assigned to exactly one station.
- The time of any station cannot be greater than cycle time of the line.
- Operations must be assigned to stations considering their priorities.

We define the following parameters:

- i and p represents operations ($i=1,\dots,n; p=1,\dots,n$)
- t_i represents the processing time for operation i
- k represents dummy operation ($k=1,\dots,K$)
- j represents stations ($j=1,\dots,m$)
- q_{ip} is defined as 1 if operation p is the predecessor of operation i and 0 otherwise.
- c is the cycle time variable and the decision variables x_{ij} are defined as

$$x_{ij} = \begin{cases} 1, & \text{if operation } i \text{ is assigned to station } j \\ 0, & \text{otherwise} \end{cases}$$

We have the following objective function

$$\min c \tag{1}$$

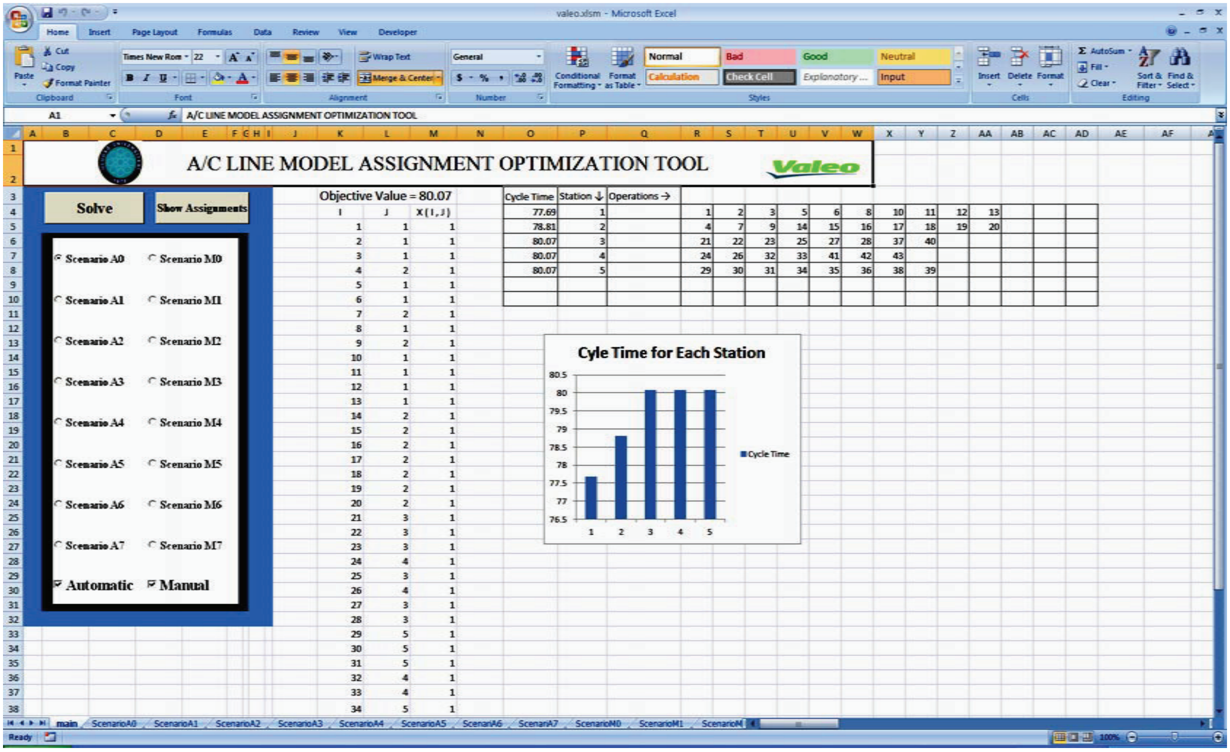
with subject to the constraints

$$\sum_{i=1}^{n} x_{ij} = 1, \quad \forall j \tag{2}$$

$$\sum_{i=1}^{n} t_i x_{ij} \le c, \quad \forall j \tag{3}$$

$$\sum_{i=1}^{n} j x_{ij} \le \sum_{p=1}^{n} j x_{pj}, \quad \forall j, \quad \forall q_{ip} = 1 \tag{4}$$

$$t_k \le c, \quad \forall k \tag{5}$$



A/C LINE MODEL ASSIGNMENT OPTIMIZATION TOOL

Objective Value = 80.07

I	J	X(I,J)
1	1	1
2	1	1
3	1	1
4	2	1
5	1	1
6	1	1
7	2	1
8	1	1
9	2	1
10	1	1
11	1	1
12	1	1
13	1	1
14	2	1
15	2	1
16	2	1
17	2	1
18	2	1
19	2	1
20	2	1
21	3	1
22	3	1
23	3	1
24	4	1
25	3	1
26	4	1
27	3	1
28	3	1
29	5	1
30	5	1
31	5	1
32	4	1
33	4	1
34	5	1

Cycle Time	Station ↓	Operations →												
77.69	1		1	2	3	5	6	8	10	11	12	13		
78.81	2		4	7	9	14	15	16	17	18	19	20		
80.07	3		21	22	23	25	27	28	37	40				
80.07	4		24	26	32	33	41	42	43					
80.07	5		29	30	31	34	35	36	38	39				

Figure 1. User Interface for Input-Output Operations

Objective function (1) minimizes the cycle time. Constraint (2) assures that each operation can only be assigned to one station and constraint (3) ensures that the total time of the operations assigned to stations is not larger than cycle time. Constraint (4) satisfied the precedence relationships. Constraint (5) states that none of the dummy operations processing time can be greater than cycle time. The model created in MPL is integrated to the MS Excel through macros in order to provide ease of use as seen in Figure 1.

4. CONCLUSIONS

In this study, we implement an integer programming model to eliminate the imbalances in an HVAC unit assembly line. Our model can find the optimal solutions in reasonable time periods, usually less than in a few minutes. To provide ease of use at real-life conditions and a flexible structure, an interface created in Microsoft Excel through which the optimal solution of the integer programming model, station utilizations can be seen as well as the inputs of the model can be changed.

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