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Research Article

A Problem-Solving Environment to Teach Students Assembly Line Balancing Techniques

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Abstract

Assembly line balancing is a production planning strategy that has been widely used in industrial applications. Most line balancing problems are known as nondeterministic polynomial time (NP-hard) problem, and they have different structures and solution methodology approaches. In this study, newly developed production planning software which is called Visual Assembly Line Balancing Software (VALBS) is introduced for educational purposes. The aim of the software is to support teaching activity for assembly line balancing techniques; facilitate understanding characteristics of different assembly lines and solution approaches, and enable to compare the results of them. The proposed VALBS is easy to use in various manufacturing environments, and suitable to support teaching line balancing procedures in undergraduate students. The software was used in classes of industrial and mechanical engineering students and feedbacks of students measured by Likert Scale survey. The results show that proposed visual software is an effective method to teach line balancing procedures.

Keywords: assembly line balancing, manufacturing systems, problem-solving, mathematical modelling

Öğrencilere Montaj Hattı Dengeleme Tekniklerini Öğretmek için Bir Problem Çözme Ortamı

Öz

Montaj hattı dengeleme, endüstriyel uygulamalarda yaygın olarak kullanılan bir üretim planlama stratejisidir. Çoğu montaj hattı dengeleme problemi, deterministtik olmayan polinom zamanlı (NP-zor) problem olarak bilinir ve farklı yapılara ve çözüm metodolojisi yaklaşımlarına sahiptir. Bu çalışmada, Görsel Montaj Hattı Dengeleme Yazılımı (GMHDY) adı verilen yeni geliştirilen üretim planlama yazılımı, eğitim amaçlı olarak tanıtılmıştır. Yazılımın amacı, montaj hattı dengeleme teknikleri için öğretim faaliyetlerini desteklemek, farklı montaj hatlarının ve çözüm yaklaşımlarının özelliklerini anlamak ve sonuçlarının karşılaştırılmasını sağlamaktır. Önerilen GMHDY, çeşitli üretim ortamları için kullanımı kolay ve lisans öğrencileri için montaj hattı dengeleme yöntemlerinin öğretimini desteklemektedir. Yazılım, endüstri ve makine mühendisliği öğrencilerine kullandırılmış ve öğrenci geri bildirimleri, Likert ölçekli anket ile değerlendirilmiştir. Sonuçlar, önerilen görsel yazılımın hat dengeleme yöntemlerini öğretmek için etkili bir araç olduğunu göstermektedir.

Anahtar Kelimeler: montaj hattı dengeleme, üretim sistemleri, problem-çözme, matematiksel modelleme

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1. Introduction

In recent years, there has been an increasing interest in educational software (Siemer, 1998). Also, several technology strategies have been used for many years in order to enhance teaching and learning processes in engineering education (Kayssi et al., 1999). Over these years, computer programs, which have different specifications, have been developed using to get the attraction of students (Siller et al., 1999, Ong et al., 2004). Some of these programs are also web-based software (Robinson and Carmical, 2005). These educational programs have been used effectively for teaching activities in many engineering field such as mining engineering (Akkoyun, 2011; Akkoyun, 2017), computer science engineering (Barua, 2001; Ochoa et al., 2003; Berenguel et al., 2016), control engineering (Rampazzo et al., 2017; Mendez et al., 2006; Aliane, 2010), chemical engineering (Schmid and Ali, 2000; Johnson and Singh, 2019; Binous and Shaikh, 2015), fluid mechanics (Pieritz et al., 2004), electrical and electronics engineering (Zavalani, 2015; Cobos and Roger, 2019), metallurgy (Ong and Mannan, 2002), optimization (MacDonald, 1995; Lazaridis et al., 2007) and industrial engineering (Lau et al., 2006; Baykasoğlu et al., 2017).

There are lots of complex subjects and methods, which must be taught in industrial engineering education, and visualization of these elements can directly affect the intelligibility of the courses. Production planning is one of these courses and includes many scheduling and balancing problems and techniques in industrial engineering education. In mass production, assembly is one of the main operations used to get any sort of product. Assembly line balancing (ALB) is a design problem for production planning that consists of precedence relations, task times, optimal task assignment, etc (Scholl and Becker, 2006). Using assembly lines to perform assembly operations can provide greater production efficiency in production environments (Scholl et al., 2009). Çevikcan et al. (2019) presented disassembly line balancing problem with multi-manned stations. Çevikcan (2016) presented mathematical models and algorithms to solve multi-model walking-worker assembly line balancing problem. Sivasankaran and Shahabudeen (2014) presented a comprehensive review of the literature on assembly line balancing. Boysen et al. (2007) provide a classification scheme of assembly line balancing.

There have been several reported efforts to use simulations to teach line balancing. Mazziotti et al. (1993) designed an assembly line balancing decision trainer to support the users' line balancing skills. In that simulation, they focused on a manual assembly line that produces textile products.

Hesieh (2009) proposed a web-based problem-solving environment to teach assembly line balancing. The proposed analytic and simulation models were evaluated by 67 students and the system helped to visualize assembly line balancing concepts.

Baykasoğlu et al. (2017) presented an excel-based assembly line balancing program which is called a quick ergonomic assessment technique. The aim of the program is to support teaching ergonomic risk assessment techniques, characteristics of different techniques and enable them to compare the results of techniques for university students. Three well-known ergonomic risk assessment techniques are coded and applied to a company. The results show that the manufacturing environment could be analyzed easily by using the techniques in the proposed program.

Ilic and Cvetic (2012) proposed educational software solution approaches to enhance solving assembly line balancing problems. As a result of this study, it was understood that the presented programs facilitated an understanding of assembly line balancing problems.

Zhang and Cheng (2010) presented a mathematical model based solution technique for a simple assembly line balancing problem. They have solved this mathematical model via Lingo 9.0 and presented an illustrative example.

Fish (2005) have provided a mini representation of assembly line balancing problems with DUBLO® (a larger version of LEGO® building blocks) blocks. Assembly line issues, such as quality, product assembly, bottleneck, task times, and unbalanced workstations are presented through this activity. It has been shown to make a positive contribution as a learning mechanism in the experiments with undergraduate students.

Bayley (2018) presented an active learning activity for teaching line balancing that addresses some shortcomings. They have described an activity to teach assembly line balancing that using special game sets to illustrate product assembly. Also, Snider et al. (2017) proposed a student peer evaluated line balancing competition exercise that challenges student groups to design a feasible and efficient assembly line.

As seen in the literature, there are various studies aimed at understanding and balancing the concept of the assembly line. The main objective of these studies are what assembly line balancing problem is and the solution methods. Some of these studies aim to teach existing mathematical modeling methods for problem-solving. In some studies, it is aimed to explain the assembly line balancing problem visually. However, when the literature researches are analyzed, it is seen that assembly line balancing problems are not examined both as a heuristic solution method, mathematical model and visualization as a whole in educational activities. In this study, new developed production planning software which is called Visual Assembly Line Balancing Software (VALBS) is introduced for the first time to address this gap. The aim of the software is to support teaching activity for assembly line balancing techniques; facilitate understanding characteristics of different assembly lines and solution approaches, and enable to compare the results of them.

2. Visual Assembly Line Balancing Software Design

Visual Assembly Line Balancing Software is designed to teach line balancing and related solution methods using different environments. The software is coded in C# programming language, and Gurobi 8.0 is used to solve and show the mathematical models for assembly line balancing. In the software, we have two basic topics for solution approaches. One of them is a heuristic procedure and the other one is mathematical modeling. In addition, in a visual balancing procedure, there are direct solutions and step by step solution approaches. The welcome screen of the program is in Figure 1.

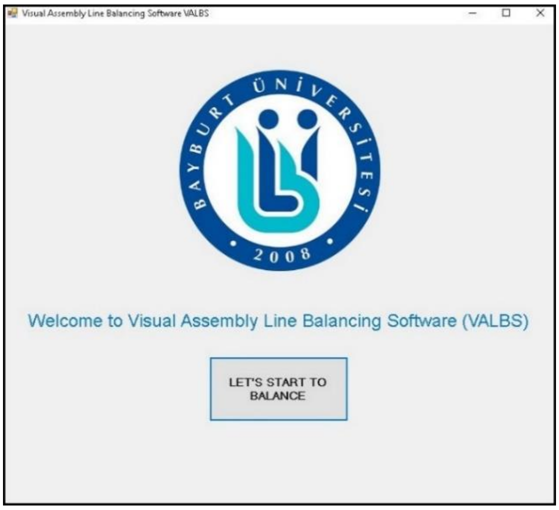

Figure 1. Welcome window of the software

With the “Let’s Start To Balance” button, the software is directed to the user to the problem window. In this part of the software, there are 25 well-known assembly line test problems. File names, problem names, task numbers, minimum, maximum and total task times for these test problems are given in this window. Within this window, the user can proceed with selecting any of these popular test problems in the literature. At the same time, in addition to these test problems, the user can define his/her own problem in the program. In this way, the sample test problems were flexed, and new test problems were allowed to be defined.

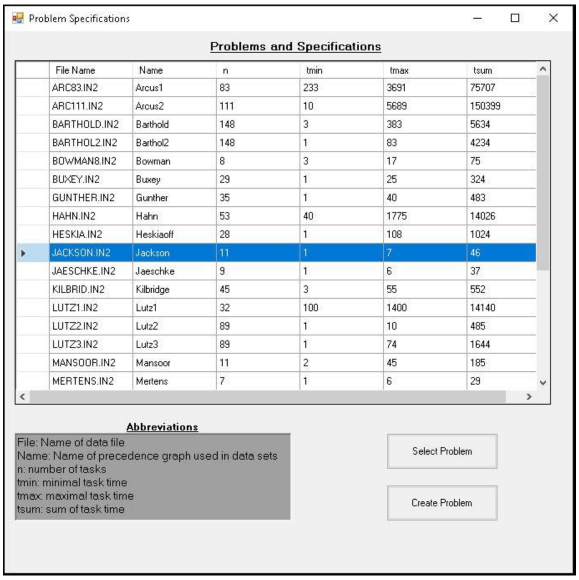

Figure 2. Problem specifications window of the software

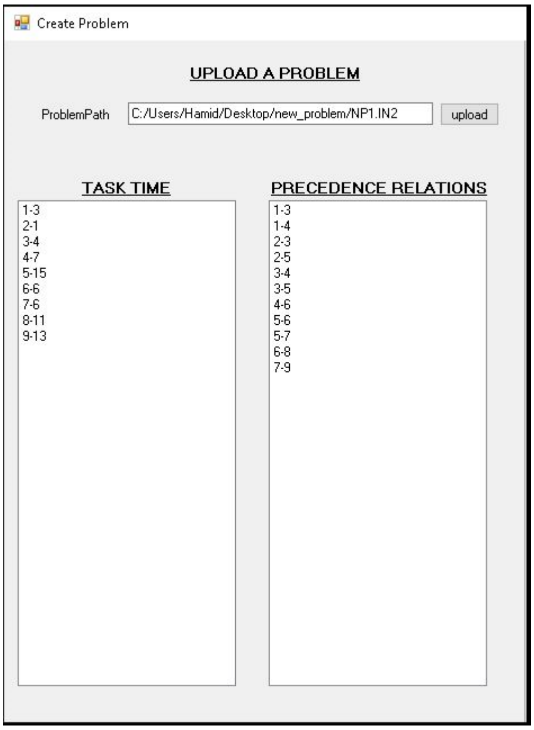

Figure 3. Problem creation window with uploading method

Figures 3 and 4 are problem-creating windows. As a primary, you can easily upload the test problems that you have already prepared for the software as seen in Figure 3. This will save you time to create and test problems. At the same time, users will be able to design the problems they want and save them for later use. The name of this method is the uploading method. Uploading window shows the task times and data on priority relationships. Thus, the user has the chance to check the entered data again.

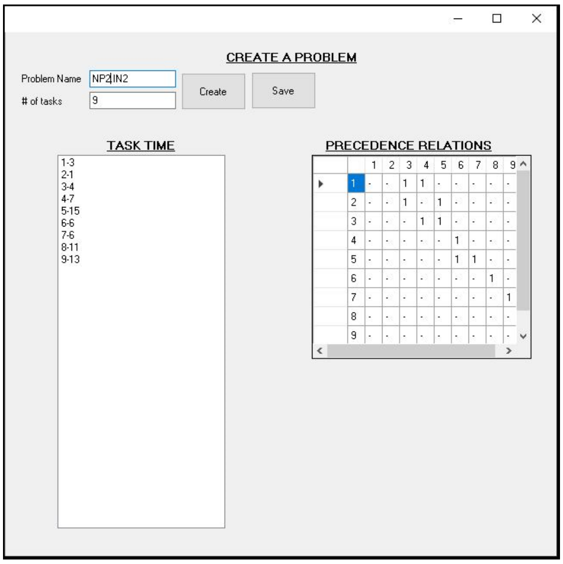

Figure 4. Problem creation window with the matrix method

Another problem installation method is the matrix method as seen in Figure 4. In this method, the user defines the precedence relationships of the problem in a precedence matrix. In this screen, the user first gives a name to the problem in the appropriate format. Then, the user enters the number of tasks for the problem to be created. Thus, the program will form the precedence matrix. Figure 4 shows the creation of a problem consisting of 9 tasks and named NP2.IN2. As can be seen from the same figure, the generated priority diagram is a two-dimensional matrix. In this way, the user defines the precedence relationships for this problem from this matrix.

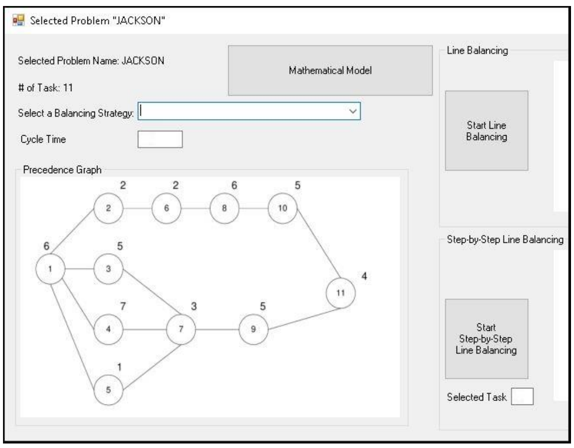

Figure 5. Problem solution window

After defining the problem or selecting the problem, the solution screen is displayed as seen in Figure 5. In this screen, first of all, information about the selected test problem is displayed. The test problem chosen as an example in this section is Jackson (1956). In this screen, the priority diagram is shown, and the cycle time required for the solution is defined. The solution window contains two types of solution methods. The first solution method is heuristic solution methods as seen in Figure 6. Some of the algorithms commonly used to solve assembly line balancing problems in the literature are coded. Most of the following rules are collected from Akyol and Baykasoğlu (2019). The computer method of sequencing operations for assembly lines (COMSOAL) method is collected form Arcus (1965).

Figure 6. Heuristic methods

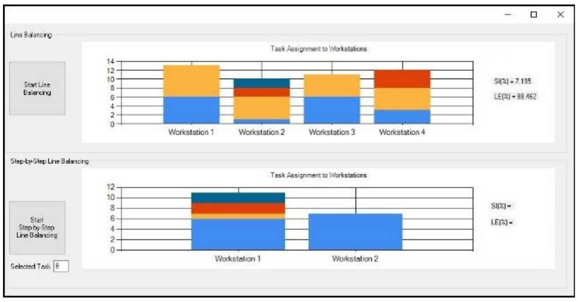

Figure 7. Line balancing screen for the selected heuristic method.

After the solution method is selected, the solution is started with “Start Line balancing” or “Start Step-by-Step Line Balancing” buttons as seen in figure 7. “Start Line Balancing” performs assembly line balancing according to the selected method and gives

Line Efficiency (LE) and Smoothness Index (SI). It is also visualized the tasks assigned to workstations. Thus, important situations such as capacities of workstations or bottlenecks can be easily detected by the user. “Start Step-by-Step Line Balancing” performs assembly line balancing according to the selected method step by step. This makes it easier for the user to understand the assignment operation of the selected algorithm. When the assignment is done, the software performs SI and LE calculations for the assembly line.

In assembly line balancing problems, one of the complex situations for students is to introduce the mathematical model. Students can create the mathematical model and solutions with the help of software as seen in Figure 8. In this study, a simple assembly line balancing Type 1 (SALBP-1) problem is discussed. The mathematical model of Patterson and Albracht is used for the SALBP-1.

Patterson and Albracht formulated a binary integer programming model for the SALBP-1 to minimize the number of workstations. Consider a work with a series of tasks i= {1, 2, ... , I} to be assigned to a number of workstations j = {1, 2,... , J}. The objective function is to minimize the number of workstations (W_j). t_i is the time required to perform the task t. The theoretical cycle time is symbolized as C. WS_j refers to the subset of all tasks that can be assigned to workstation j, and $||WS_j||$ refers to the number of tasks in subset WSj . P_i is the set of tasks that must proceed with the task i, and S_i is the set of tasks that must succeed task i. x_{ij} is a decision variable to represent the assignment of task i to station j. The mathematical model for the SALBP-1 can be written as [35]:

$$minimize\ z = \sum_{j=1}^{J} W_j \quad (1)$$

Subject to:

$$\sum_{j=1}^{J} x_{ij} = 1, i = \{1, 2, \dots I\} \quad (2)$$

$$\sum_{i=1}^{I} t_i x_{ij} \leq C, j = \{1, 2, \dots J\} \quad (3)$$

$$\sum_{j=1}^{J} j x_{nj} \leq \sum_{j=1}^{J} j x_{mj}, for\ \forall(n, m) \in P \quad (4)$$

$$\sum_{i \in WS_j}^{J} x_{ij} \leq ||WS_j|| W_j, j = \{1, 2, \dots J\} \quad (5)$$

$$\forall x_{ij}\ and\ W_j = \{0, 1\} \quad (6)$$

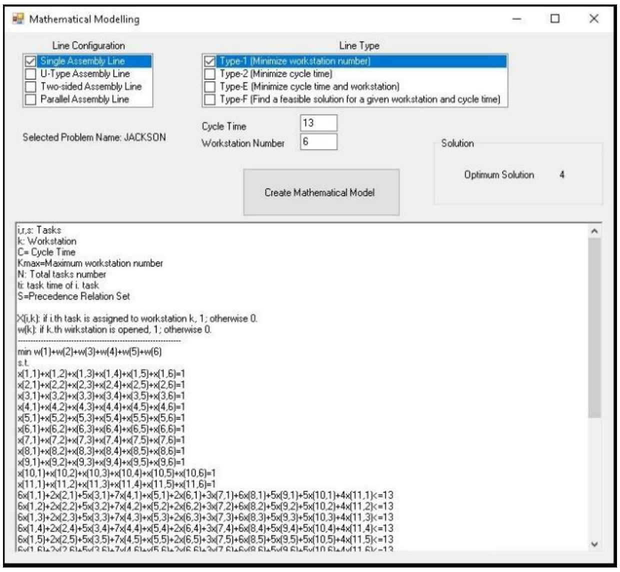

Figure 8. Mathematical modeling screen of the software

3. Application and survey feedback

VALBS was developed in 2017 and since then it has been used in several lecturers in engineering departments to give information about assembly line balancing such as test problems in the literature, precedence relations, creating test problem, solution approaches, mathematical models, line efficiency, smoothness index, and bottleneck. In the lessons, it was used more effectively and in communication by changing the assignment strategies or using mathematical models to reduce the number of stations.

Although positive results were obtained with this software, a Likert scale survey was also conducted in order to be able to prove scientifically. Likert scale survey was prepared and applied into two departments in Bayburt University. 19 students in the industrial engineering department and 22 students in the mechanical engineering department participated in the survey. The questions of these surveys and their results for students are summarized together in Table 1.

Table 1. Summary of Likert Scale Survey Results

		Industrial Engineering Department		**Mechanical Engineering Department**	
		Mean	**Std. Dev.**	**Mean**	**Std. Dev.**
1	I prefer books or conventional educational tools	1,63	0,68	1,59	0,67
2	It is easy to input data and generate problems	4,53	0,90	4,36	0,95
3	It is helpful to understand the assembly line balancing problems and solution techniques	5,05	1,03	4,95	1,00
4	It helps to increase my interest in the course	5,32	0,89	5,45	0,74
5	It would be nice to have such software for more lessons	5,21	0,85	5,18	0,80
6	The visuality of the program made me understand the subject better	5,42	0,77	5,50	0,74
7	In fact, assembly line balancing problems were not very difficult.	4,79	0,85	4,95	0,90
8	The use of the program is very complicated and difficult	1,68	0,58	1,73	0,55

4. Results

The software was tested in the production planning and control course of industrial and mechanical engineering students at Bayburt University. A total of 41 students (19 from industrial engineering and 22 from mechanical engineering) participated in the survey. Although the knowledge levels of these two departments were different, the survey results were similar.

Based on these results, we can conclude that VALBS is effective as a tutorial for the assembly line balancing problem and that the feedback by the students is positive. The survey results are favorable and they encourage lecturers to code or use different software tools for educational purposes.

The software can be discussed in more detail in the future. For example, assembly line problems with different features can be included in the software or meta-heuristic methods can be used as solution methods.

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