

COMPARISON OF THE OPTIMAL PERFORMANCE OF ASSEMBLY LINE CONFIGURATIONS WITH SIMPLE ASSEMBLY LINE BALANCING MODELS

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Abstract: Assembly line balancing models determine the optimal assignment of task to workstation when one, or a few types of products are produced continuously in large quantities. The problem is NP-hard; therefore the solution of large problems can be difficult and time consuming. As a consequence of the development of computer technology, however, small and medium size practical problems can be solved easily even on an average laptop computer. This paper shows how the performance of different line configurations of an electrical motor assembly process can be examined with simple assembly line balancing models.

INTRODUCTION

Assembly line balancing (ALB) problems occur where several indivisible work elements (tasks) are to be grouped into (work)stations along a continuous production line. Workers may work at each station, and in case of efficient allocation of tasks to workstations, the number of workers and consequently the cost of operation can be decreased. ALB problems are typical for example in automobile, in bicycle and in electronic industry (assembling refrigerators, televisions, etc.), but the operation of some service systems is also very similar to assembly line operations.

Tasks cannot be allocated to the stations arbitrarily. Cycle time constraints, precedence relations – generally visualized by a precedence graph –, zoning conditions, technological and logical requirements may influence the optimal assignment. Even considering these restrictions many feasible solutions may exist for the allocation of tasks to stations and optimization models can be used to find the best task assignment. The assembly line problem is NP hard; therefore, a considerable amount of research effort was made in the past to reduce computational work [1], [4]. As a consequence of the development of computer and information technology, however, even medium size ALB problems can be solved in a reasonable time frame [3].

Several papers are published about the practical application of ALB models for optimizing task assignment to workstations (See for example [2], [3] and [5].). In this paper we show how the performance of assembly line configurations can be compared and evaluated with the help of simple ALB models in case of a small electrical motor assembly process. First, the product and the outline of the production process are introduced. Next, the applied ALB model is defined. Finally, the solution of the model and the interpretation of the results are presented.

THE SAMPLE ASSEMBLY PROCESS

The assembly process we examined in this paper belongs to Phoenix Mecano, which is a multinational firm group with central headquarters in Switzerland, manufacturing plants throughout the world. In 1993 the group established its most important subsidiary, Phoenix Mecano Kecskemét Kft. The Hungarian plant manufactures plastic, aluminium and polyester enclosures, electronic motors and transformers, membrane keyboards and design foils, actuation devices and control units, drive units, plastic components, protection and partitioning systems.

The company is strongly committed to the application of lean techniques and to continuous improvements in order to increase productivity. The application of ALB models to determine the most efficient line configuration was in line with their policy of applying any technique which can help evaluating the suggested organizational changes.

The sample product we use in the following to illustrate the application of ALB models is a special hospital bed drive. This drive is an electrical motor which is used for adjusting the slope of a hospital bed. The list of tasks of the assembly process, the corresponding task times, and the immediately preceding task of each task is given in Table 1.

Table 1.
Tasks, task times and precedence relations of the sample product

Task	Description of task	Task time (sec)	Immediately preceding task
A	Assembling the spindle	52	-
B	Placing the spindle into the grease gun	10	A
C	Greasing the spindle	13	B
D	Pressing the cap on the duct by hand and placing it into the holder	8.5	-
E	Pressing the cap	8.5	D
F	Screwing and greasing the cap	32	E
G	Assembling casing + BGS + straddle	63	C, F
H	Mounting the cable (power supply)	25	G
I	Binding and coupling the engine power supplies, inserting the cable holder blank	41	H
J	Greasing and housing the engine	15	I
K	Screwing the engine	15	J
L	Drilling and screwing the retainer screw	13	K
M	Rolling in the engine cap and the lift pipe	15	L
N	Placing the gear on the tester device	25	M
O*	Testing	25	N
P	Pulling, corking and labeling the gear	52	O
Q	Cleaning and placing the gear in the carton	31	P

Note, that for confidential reasons we changed the relevant data of the process. This change, however, does not influence the main characteristics of the results.

Based on the data of Table 1 the precedence graph of the product can be prepared (See Figure 1.).

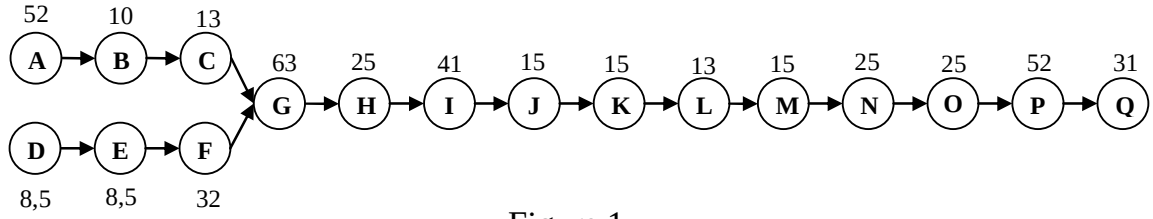


Figure 1.
The precedence graph of the sample product

The product is currently produced in an assembly line consisting of 4 workstation cells. Workers stand at the four positions of a table and pass around the product. For several work organizational reasons the company has decided to apply 7 workstation long U shaped lines. The main reason of this change is that they want to take advantage of the learning curve effect. If the line is longer, a worker performs more frequently the same task, consequently, the exponential decrease of task times is better exploited.

THE MATHEMATICAL PROGRAMMING MODEL

The objective is to determine the maximum production quantity for two different line lengths; for the original 4 workstation line, and for the suggested 7 workstation line. This problem can be solved by using the second type of simple assembly line balancing model (SALBM-2) which minimizes cycle time for a given number of workstations. The notations used in the model are summarized in Table 2. The model is the following,

$$\text{Min } T_c \quad (1)$$

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

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

$$\sum_{j=1}^J j \cdot (x_{qj} - x_{pj}) \geq 0 \quad (p, q) \in R \quad (4)$$

$$x_{ij} = 0 \quad j < LJ_i; j > UJ_i; i = 1, \dots, I \quad (5)$$

$$LJ_i = \left\lceil \frac{t_i + \sum_{k \in P_i} t_k}{UB(T_c)} \right\rceil \quad (6)$$

$$UJ_i = J + 1 - \left\lfloor \frac{t_i + \sum_{k \in S_i} t_k}{UB(T_c)} \right\rfloor \quad (7)$$

SALBM-2 minimizes the cycle time (1), which is equivalent to the maximization of the production rate. Decision variable x_{ij} equals to one if task i is assigned to station j , otherwise it equals to zero. Constraints (2) ensure that the total time in station j does not exceed the cycle time (T_c). Equations (3) guarantee that each task is performed. Precedence relations are specified by (4) where task p immediately precedes task q . The number of the decision variables are decreased by (6) and (7) by limiting the feasible set of workstation indices. Note that a more efficient filtering of the workstation indices is possible with the model developed by Pastor and Ferrer [6] recently. The size of the model in our case, however, does not require the application of this sophisticated method.

Table 2.
Notations

<i>Indices:</i>	
i	= index of tasks ($i=1,\dots,I$),
p	= index of a subset of tasks,
q	= index of a subset of tasks,
k	= index of a subset of tasks,
j	= index of workstations ($j=1,\dots,J$).
<i>Parameters:</i>	
I	= number of tasks,
J	= number of workstations,
t_i	= time necessary to perform task i (task time),
T_c	= cycle time of the assembly line,
T	= total available time for production,
LJ_i	= the earliest workstation which can be used by task i as a consequence of preceding tasks of task i ,
UJ_i	= the latest workstation which can be used by task i as a consequence of succeeding tasks of task i ,
Q	= production quantity,
$UB(T_c)$	= upper bound of the cycle time,
<i>Sets:</i>	
R	= set of the pair of indices which belong to tasks with precedence relations; that is, $(p;q) \in R$ if task p immediate precedes task q ,
P_i	= index set of those tasks which must be finished before task i is started,
S_i	= index set of those tasks which cannot be started before task i is finished,
<i>Decision variables:</i>	
x_{ij}	= 0-1 decision variable; if $x_{ij}=1$, then task i is assigned to station j , otherwise $x_{ij}=0$.

We solved the above SALBM-2 with the data of the sample product. Even in case of 7 workstations the required number of variables is only 120. The optimal solution of this small model can be obtained easily with any mathematical

programming software in a few seconds. We used MS Excel to store input data and output results, and solved the model with the Lingo mathematical programming software.

ANALYSIS OF THE RESULTS

The results of the solution of the SALBM-2 for the 4 and 7 workstation line configurations are summarized in Table 3.

Table 3.
Comparison of line configuration results

Parameters and performance measures	Original line	Suggested line	%
Number of workstations	4	7	42.86
Cycle time (sec)	124	81	-53.08
Maximum production quantity	212,9	325,9	34.67
Assignment efficiency	0,895	0,783	-11.20
Quantity per worker	53,23	46,56	-14.33

The cycle time of the short line is 53.08 per cent smaller than that of the longer line. This result is obvious, because if the same amount of work is performed by more workstations, then generally the station time of workstations, and consequently, the cycle time decreases.

The maximum production quantity is 34.67 per cent smaller in the case of the short line than in the case of the long line. If products are produced at a faster rate (smaller cycle time), then higher quantity is produced in a given period.

Assignment efficiency is related to capacity utilization. The 11.2 per cent decrease of capacity utilization of the long line indicates that capacity utilization is better in the short line. This result is also supported by the quantity per worker results. One worker produces more products in the short line than in the long line. Consequently, when learning effect is not considered, that is, constant task times are assumed, the application of the longer line is not justified.

The experimental 7 workstation lines, set up at the company, however, showed better results in case of the longer lines. This can be explained by the presence of learning effect. If an exponential (Wright type) learning curve is used, it is easy to show that the quantity per worker result is equal for both lines when learning rate is approximately 85 per cent. We assume in this case that the cycle time provided by SALBP-2 is exponentially decreasing with the learning rate.

Learning effect, however, does not prevail infinitely because workers are rotated to avoid the unfavorable effect of repetitive work. On the other hand if task times decrease as a consequence of the learning effect the reallocation of tasks to workstations may further reduce cycle time. The reallocation of tasks can be done based on the results of SALBP-2 when it is solved with reduced task times.

We can conclude that if learning effect is not present, the application of the 7 workstation line is not justified. If learning effect really prevails, then a proper

organization of work is required, which exploits efficiently the task time reduction effect.

CONCLUSION

In this paper we showed, how the comparison of two assembly line configurations for the assembly process of a hospital bed drive can be compared. The paper presents the main data of the assembly process, the details of the mathematical model, and some relevant results and conclusions.

The objective of the company is to organize longer lines in order to exploit learning curve effect. We showed that if constant task times are used, the shorter line performs better than the longer line. If, however, cycle time decreases exponentially as a consequence of learning effect, the longer line may perform better. To determine those conditions, which must be satisfied to turn the longer line more efficient than the shorter line is a topic of our further research.

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