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A novel mathematical model for manpower scheduling in break (relief) times in mixed model assembly lines

Asefeh Hasani-Goodarzi[a]*,Masoud Rabbani[a], Neda Manavizade[a]

[a] *Department of Industrial Engineering, Faculty of Engineering, University of Tehran, Tehran, Iran*

Abstract

In real industries there are some limitations on the number of workers and in some situations it is unavoidable to schedule employees for break times to minimize labor cost. In this paper, the problem of manpower scheduling in break times for employees working in mixed model assembly lines (MMALs) is investigated, which has not been studied to the best of our knowledge. We assume three breaks a day, one for lunching and two breaks for short resting. It is also essential to attend the station by the minimum number of workers while manufacturing desired rate of production.

*Keywords:*Mixed-model assembly line, manpower scheduling, break time, mathematical model;

1. Introduction

Mixed-model assembly line (MMAL) is increasingly accepted in industry to deal with the variety in customer's preference. It is possible to assemble different models on a same line, without line stop or a big delay for changeover or changing facilities (Bautista and Cano, 2008). In this way, mass-production techniques can be applied for a family of models when the demand for each model does not justify a dedicated production system (Chakravarty and Shtub, 1992).We considers humanitarian aspect of these systems, which has an important effect on total cost of the system because of labor cost. The importance of due date setting and satisfying customer demand is unavoidable in company performance, thus the production rate should be kept in a stable state that is able to reply to demand fluctuations. There is no research that considers break times in MMAL to the best of our knowledge and most man power and shift scheduling researches have investigated service companies. The ultimate aim of manpower scheduling is to seek the shift rosters that adapt to time-varying demand, so that it controls the costs and satisfies all executive restrictions (Castillo et al., 2009).Generally, the optimal employee/shift scheduling problem arises in some situations with a variety of service delivery settings, such as telephone companies, airlines, hospitals, banks, police departments, transportation companies, fire departments, etc (Aykin, 1996). The importance of this kind of scheduling reveals in some organization with fluctuating customer demand and variable workforce availability, in which improper employee scheduling can lead to costly under/over staffing. Overstaffing results in inflated payroll costs and understaffing (inadequate staffing) leads to poor customer service, causing reduced customer conversion rates and a potential loss of profit. It is clear that for any service organization it is important to schedule its

* Corresponding Author name. Tel.: +98-916-662-1292
E-mail address:asef.hasany@ut.ac.ir

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manpower in an efficient manner to minimize labor costs while providing the desired service level. For other companies that use man power in order to produce merchandise it also should receive enough attention.
Baker (1976) classified the personnel scheduling problems into three categories: days-off, shift and tour scheduling problems. Days-off scheduling problems deal with the assignment of work and rest days to employees over a given planning horizon (e.g. nurse scheduling). Shift scheduling problems deal with the assignment of starting and finishing times to employees, and possibly the placement of relief and meal breaks within each shift which is in many service organizations with variable demand throughout the day. Tour scheduling problems deal with conditions in which both daily shift and days-off schedules must be determined simultaneously. In shift scheduling problem employees are assigned to various shifts specified by shift type, length (e.g., four-hour part-time, nine-hour full-time), shift start time, and the number and length of relief/ lunch breaks. To provide flexibility in such a problem, break windows (time intervals within which employees must start and complete their breaks) are often specified, which lessen the total staffing cost and the number of employees needed (Aykin, 1996).According to Cai and Li (2000) the staff scheduling problem is generally very difficult to solve, even when it is encountered in a simplified manner containing a single criterion and a homogeneous skill. In fact, the problem has been known to be NP-complete (Bartholdi, 1981). The number andduration of breaks an employee takes are determined by many factors including legal restrictions (work stretch duration restrictions), company policies, union agreements and humanitarian factors (Aykin, 2000). Generally, an employee that works seven to nine consecutive hours a day is given one lunch break and two rest (relief) breaks, one before and one after the lunch. Shifts with shorter working hours may be assigned fewer breaks. According to Aykin (1996) the length of a lunch break is usually a half hour to an hour and a rest break 15 to 30 minutes.Workforce scheduling and simultaneous allocation in production and service environments have been extensively taken into account by many researchers, but they have not received much attention in mixed model assembly lines. Cerulli et al. (1992) presented a mathematical model in order to schedule and allocate the specific number of employees. Emmons and Fuh (1997) constructed a model for scheduling full-time and part-time workforce regarding vacations and weekends. The shift scheduling problem with multiple relief, lunch breaks and break windows was also investigated by Henderson and Berry (1976). Alfares (1998) proposed a two-phase algorithm based on mathematical models cyclic days-off scheduling.Beaumont (1997) considered the problem of workforce scheduling with the objectives of determining the number of staff to employ and the times at which shifts should start and the amount of demand should be met by contractors. He presented a mixed integer programming (MIP) to solve the problem. Cai and Li (2000) considered the problem of staff scheduling with mixed skills and formulated the problem as a multi-criteria optimization model with the objectives of minimizing the total cost for assigning staff to meet the manpower demands over time, maximizing the surplus of staff with almost same level of assigning cost, and minimizing the variation of surplus staff over different scheduling periods. Aykin (1996)considered multiple rest and lunch breaks, and also break windows in shift scheduling problem and presented an integer programming model for the problem. Rekik et al. (2010) considered a shift scheduling problem including different forms of flexibility in terms of shift starting times, break lengths and break placement. Bhatnagar et al. (2007) presented a framework that balances the significant tradeoffs and helps managers in devising a strategy for applying contingent workers in a complex assembly environment. They presented a linear programming model (LP) in order to determine the optimal allocation of permanent and contingent workers to all sub-processes. They considered distinct manufacturing sub-processes, hierarchical or nested workforce skills, regular and overtime capacity, and impact of learning. Shahnazari-Shahrezaei et al. (2011) presented a novel bi-objective manpower scheduling problem with the objectives of minimizing the penalty incurred by the employees' assignment at lower skill levels than their real skills and maximizing the employees' utility by assigning them at desired skill levels in some shifts/days. They considered two classifications for employee's specialty and three skill levels in each specialization.

2. Problem description

The assembly line is able to produce a variety of models, so all the operators are multi skilled and it is possible to process required tasks on workstations. By applying an assumption considered by Aykin (1996), employees receive one half-hour lunch break and two 15-minute relief breaks in a working day containing nine hours for each shift. In this paper whenever we call a break as the second (B2) we mean the break after the lunch. There are permanent and contingent workers on the assembly line and contingents are used when required. When workers begin their break times the producing line is not allowed to reduce the output rate, so contingent workers are used. Contingent workers are divided into two groups, junior and senior operators. The yield of senior operators is more than the junior ones. The number of permanent employees in each station is known in advance and is denoted by b_j.Relief and lunch breaks must start and be completed within the specified time windows. The supposed assumptions are as follows.

- Shift must receive exactly three sub-breaks; each sub-break constitute of 15 minute-periods that are denoted as t (e.g.t=1,…, 36 is used to show a 9-hour-shift).
- The sub-break in the second position that is considered as lunch break must be longer than the ones in the first and third positions, which means that for lunch break two consecutive periods should be assigned to each worker to start they break time.
- The output rate of permanent employees is considered as a standard rate and other workers' output is compared with it.
- $B1$, $B2$ and BL are the set of possible periods for the first, second and lunch break windows and $B=B1 \cup B2 \cup BL$.T_{BL}isdenoted as the last period in the window assigned to lunch break.

2.1. Indices and Parameters

i	Index for break times (i=1, 2, 3 show the first, second and lunch break, respectively)
m	Index for Product model (m=1,…,M)
j	Index for station (j=1,…,J)
O	Index for employee (o_j: the o-th operatorof station$j$)
t	Index for the relief period considered in each break window
b_j	Number of permanent employees in station j
α_{mj}	Relative output rate (compared with a permanent worker) for each senior operator in processing model m in station j
β_{mj}	Relative output rate (compared with a permanent worker) for each junior operator in processing model m in station j
C_{ij}	Cost of assigning a senior operator in break time i to the station j
C'_{ij}	Cost of assigning a junior operator in break time i to the station j
Vr	Maximum capacity of relief room
Se	Maximum number of contingent workers (senior)
Ju	Maximum number of contingent workers (junior)

2.2. Variable

Y_{ijt}	Number of senior worker assigned to break i, station j for period t
Z_{ijt}	Number of junior worker assigned to break i, station j for period t
X_{ojt}	Binary variable: 1 if employee o in station j goes to the first break at period t
X'_{ojt}	Binary variable: 1 if employee o in station j goes to the second break at period t
X''_{ojt}	Binary variable: 1 if employee o in station j goes to lunch break at period t
U_{jt}	Numbers of employees of station j starting their first relief break in period t
V_{jt}	Numbers of employees of station j starting their second relief break in period t
W_{jt}	Numbers of employees of station j starting their lunch break in period t

It is assumed that $X''_{oj0} = 0$, which means that for lunch break the first period to be planed for each employee should be in the time window. It is also true for periods that exceed the upper bound of time window.

2.3. Mathematical model

A mixed integer linear programming is presented in this section as the model to schedule workforce in break times.

$$\mathbf{Min} \sum_{i} \sum_{j} C_{ij} \times \sum_{t \epsilon B} Y_{ijt} + \sum_{i} \sum_{j} C'_{ij} \times \sum_{t \epsilon B} Z_{ijt} \tag{1}$$

s.t.

$$\sum_{o} \sum_{t \epsilon B1} X_{ojt} - \sum_{t \epsilon B1} V_{jt} = 0 ; \quad \forall j \tag{2}$$

$$\sum_{o} \sum_{t \epsilon B2} X'_{ojt} - \sum_{t \epsilon B2} U_{jt} = 0 ; \quad \forall j \tag{3}$$

$$\sum_{o} \sum_{t \epsilon BL} X''_{ojt} - 2 \sum_{t \epsilon BL} W_{jt} = 0 ; \quad \forall j \tag{4}$$

$$\alpha_{\mathrm{mj}} Y_{1jt} + \beta_{\mathrm{mj}} Z_{1jt} \geq V_{jt}; \quad \forall t \epsilon B1,\ j,\ m \tag{5}$$

$$\alpha_{\mathrm{mj}} Y_{2jt} + \beta_{\mathrm{mj}} Z_{2jt} \geq U_{jt}; \quad \forall t \epsilon B2,\ j, m \tag{6}$$

$$\alpha_{\mathrm{mj}} Y_{3jt} + \beta_{\mathrm{mj}} Z_{3jt} \geq W_{jt}; \quad \forall t \epsilon BL,\ j, m \tag{7}$$

$$\sum_{t \epsilon B1} X_{ojt} = 1 ; \ \forall j, o \tag{8}$$

$$\sum_{t \epsilon BL} X'_{ojt} = 2; \ \forall j, o \tag{9}$$

$$\sum_{t \epsilon B2} X''_{ojt} = 1; \ \forall j, o \tag{10}$$

$$\text{if } X''_{ojt} = 1 \text{ then } X''_{oj(t-1)} + X''_{oj(t+1)} = 1; \ \forall\, j, o, t = 1, \dots, T_{BL} - 1; \tag{11}$$

$$\text{if } X''_{ojT_{BL}} = 1 \text{ then } X''_{oj(T_{BL}-1)} = 1 ; \tag{12}$$

$$\sum_{j} V_{jt} \leq Vr \forall t \epsilon B1; \tag{13}$$

$$\sum_{j} U_{jt} \leq Vr; \quad \forall t \epsilon B2 \tag{14}$$

$$\sum_{\mathrm{j}} W_{jt} \leq Vr; \quad \forall \mathrm{t} \epsilon \mathrm{BL} \tag{15}$$

$$\sum_{j} Y_{ijt} \leq Se; \ \forall t, i \tag{16}$$

$$\sum_{\mathrm{j}} Z_{ijt} \leq Ju; \ \forall t, i \tag{17}$$

$Y_{ijt}, Z_{ijt} \geq 0$ and integer ; $X_{ojt}, X'_{ojt}, X''_{ojt} \in \{0,1\}$ (18)

The objective function (1) minimizes the cost of assigning contingent workers for both senior and junior employees. Constraints (2- 4) determine the number of employees take their break times in period t of break window for all the relief and lunch break, respectively. Constraint (5-7) ensure that number of whole workers in each station (including contingent and permanent workers) and in each break cannot be less than a definite number, in order to satisfy customer's demand. Constraints (8- 10) show all the operators should go to the first and second relief break and also lunch break in the specified break window respectively. For lunch break two consecutive periods should be chosen by each operator, which is stated by (11) and (12). Constraint (13-15) ensure that number of workers go to break at a certain time cannot exceed the capacity of relief room. Constraint (16) and (17) state a limitation about the maximum number of senior and junior contingent workers assigned to stations, respectively and (18) defines non negativity and type of decision variables (integer or binary).

3. Experimental result

In this section, we evaluate the tractability of the proposed programming model in terms of the objective function value and the required computational time. To do this, we perform some numerical experiments on a set of randomly generated problem instances in small, medium and large sizes. The programming models were implemented in Gams 22.9 modeling language. All experiments were performed on a laptop with a Core 5 Duo CPU processor and 4 GB of RAM. A set of basic practical assumptions of the problem is expressed below. Employee assignment is assumed to be determined for 36 quarter-hour (= 4 × 9 hours) planning periods, t = {1,... , 36}. Each employee is supposed to be given one 30-minute lunch break and two 15-minute relief breaks (one before and one after the lunch break). We assume the intervals considered by Aykin [9].The ideal break start time for the first relief break is usually specified as two hours after the start of the shift, the ideal start time for the lunch break is set as four hours of work plus the first break length and ideal start time for the last break is specified as six hours plus the first and middle break lengths. We assume that all break windows are 1.5 hours long and start half an hour before the ideal break start times. Then the time window for the first 15-minute relief break is from 8:30 to 10:00, for the lunch break from 10:45 to 12:15, and for the second 15-minute relief break from 13:15 to 14:45. Thus, the lunch break for an employee may be scheduled in five different ways: from 10:45 to 11:15, 11:00 to 11:30, 11:15 to 11:45, 11:30 to 12:00, and 11:45 to 12:15. And each 15-minute relief break may be scheduled in six different ways. The shifts, ideal break start times and break windows are shown in Figure 1.

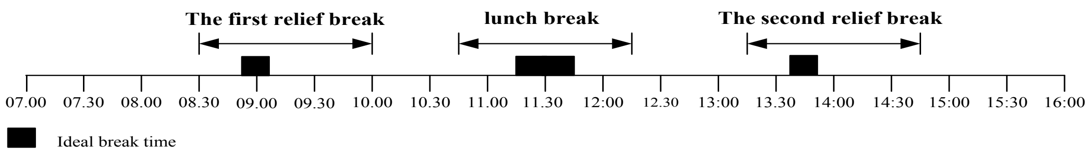

Figure 1. The ideal break times and break windows in the nine-hour shift example

We randomly generate a total of 20 problems by considering a nine-hour shift for each test problem. The model can be easily adapted for part time and also other kinds of shift problems (e.g. eight- hour shift). Table 1 indicates the intervals of generating random data.Table 2 indicates the decision variables for five problems with three workstations in the line.

Table 1. Interval used to generate model's inputs

Inputs	Uniform Distribution
number of operators in each workstation	[1, 15]
cost of assigning one senior contingent worker to a station in period t	[200, 400]
cost of assigning one junior contingent worker to a station in period t	[100, 250]
Relative output rate for each senior operator in processing model m in station j	[1, 2]

Relative output rate for each junior operator in processing model m in station j	[0.5, 1]

Table 2. Number of senior and junior workers in each station and for each period in break windows (decision variables for a set of three-station problem)

test problem	worker	Number of contingent workers in period *t*								
		B1			***B2***			***BL***		
		***j*=1**	***j*=2**	***j*=3**	***j*=1**	***j*=2**	***j*=3**	***j*=1**	***j*=2**	***j*=**
1	S	(0,0,1,0,0,0)	(0,0,0,0,0,0)	(0,0,0,3,0,0)	(0,0,0,0,4,0)	(0,5,0,0,0,0)	(1,0,0,0,0,4)	(2,2,4,0,4,0)	(1,0,0,0,1,0)	(2,3,1,0,
	J	(0,5,0,0,3,0)	(4,0,4,0,0,0)	(0,0,0,4,0,0)	(0,0,0,0,2,0)	(0,1,0,0,0,0)	(0,0,0,0,0,1)	(0,0,0,0,0,0)	(0,0,4,2,4,4)	(4,4,0,0,
2	S	(0,0,1,0,0,0)	(0,0,0,0,0,0)	(0,0,2,1,0,0)	(0,0,0,0,0,3)	(0,0,0,0,0,0)	(5,0,0,0,0,0)	(6,0,6,0,0,0)	(0,0,0,0,0,0)	(0,3,0,3,
	J	(8,0,0,0,0,0)	(0,8,0,0,0,0)	(0,0,4,0,0,0)	(0,0,0,0,0,4)	(0,0,8,0,0,0)	(1,0,0,0,0,0)	(0,0,0,0,0,0)	(0,0,0,0,8,8)	(0,4,0,4,
3	S	(0,0,0,1,0,0)	(0,0,0,0,0,0)	(0,0,0,0,1,0)	(0,0,0,0,0,0)	(0,0,0,0,0,0)	(0,0,1,4,0,0)	(4,2,4,0,0,2)	(1,0,1,0,0,0)	(0,3,0,0,
	J	(0,5,0,2,0,0)	(0,0,4,0,0,4)	(0,0,0,3,5,0)	(0,0,3,0,0,5)	(0,4,0,4,0,0)	(0,0,0,1,0,0)	(0,0,0,0,0,0)	(4,4,4,2,0,0)	(0,0,0,3,
4	S	(0,0,0,0,0,0)	(0,0,0,0,0,0)	(0,0,0,0,0,0)	(0,0,0,0,0,1)	(0,0,0,0,0,0)	(0,3,2,0,0,0)	(0,3,3,3,0,3)	(0,0,0,0,0,0)	(0,0,0,0,
	J	(8,0,0,0,0,0)	(0,0,0,8,0,0)	(0,0,9,0,0,0)	(7,0,0,0,0,0)	(0,0,0,8,0,0)	(0,1,0,0,0,0)	(0,0,0,0,0,0)	(8,0,0,0,8,0)	(0,9,0,9,
5	S	(0,0,0,0,0,0)	(0,0,0,0,0,0)	(0,0,0,1,0,0)	(0,0,0,0,1,0)	(0,0,0,0,0,0)	(0,0,0,2,1,3)	(6,0,0,0,6,0)	(1,0,0,2,0,0)	(0,0,4,0,
	J	(0,0,3,3,2,2)	(4,4,0,0,0,0)	(0,0,0,2,3,3)	(0,0,3,0,0,4)	(2,0,0,4,3,0)	(0,0,0,0,0,0)	(0,0,0,0,0,0)	(0,4,3,0,2,4)	(3,0,0,5,

In table 2 S and J show the number of senior and junior workers employed in break time i, station j and period t. for example (0,0,2,1,0,0) shows that two and one contingent workers should be assigned to period 3 and 4, respectively. Table 3 summarizes the results for 20 test problems. For each model, it reports the cost of scheduling workforce in break times and computational time of executing. It is clear that the computational time increases by increasing the number of stations. The results are presented for problems with up to 15 workstations.

Table 3. Computational result for a set of problem

test problem	*J*	*M*	b_j	*Vr*	(*Se*, *Ju*)	Obj.Value	CPU (sec)
1	3	3	(3,2,4)	8	(5,5)	16848	0.015
2	3	4	(4,3,5)	6	(8,8)	16916	0.016
3	3	5	(6,8,6)	8	(10,5)	17010	0.016
4	3	6	(7,4,6)	9	(3,9)	15997	0.016
5	3	10	(2,5,7)	10	(7,5)	17681	0.016
6	4	5	(4,3,1,2)	9	(4,5)	23800	0.015
7	4	6	(7,4,6,3)	9	(3,9)	24408	0.016
8	4	10	(2,5,7,3)	10	(4,8)	23419	0.018
9	6	5	(4,3,1,2,2,4)	15	(7,7)	37988	0.031
10	6	6	(2,5,7,3,2,3)	12	(5,9)	32075	0.016
11	6	8	(2,5,7,3,2,3)	12	(5,9)	32130	0.016
12	6	10	(2,5,7,3,2,3)	12	(5,9)	32936	0.031
13	7	5	(4,3,1,2,1,3,2)	14	(9,7)	41603	0.016
14	8	5	(4,3,1,2,1,3,2,6)	20	(8,10)	46547	0.032
15	8	6	(4,3,1,2,1,3,2,6)	18	(8,10)	46943	0.042
16	9	6	(4,3,1,2,1,3,2,6,5)	18	(8,12)	51688	0.032
17	10	6	(4,3,1,2,1,3,2,6,5,6)	20	(8,15)	57546	0.031
18	11	6	(4,3,1,2,1,3,2,6,5,6,2)	22	(8,18)	63969	0.031
19	12	6	(4,3,1,2,1,3,2,6,5,6,2,4)	25	(10,18)	70289	0.032
20	15	6	(4,3,1,2,1,3,2,6,5,6,2,4,2,3,6)	30	(15,19)	88459	0.047

4. Conclusion

There is a need to investigate humanitarian aspects in mixed model assembly lines especially in the field of manpower scheduling which have a large portion of producing cost. Workforce scheduling in break times for systems with MMAL approach and some practical restrictions is investigated in this paper. We consider three breaks a day, a lunch break and two relief breaks for a full-time shift, which can be extended for other types of shift scheduling problems. Other hint for future research is using heuristic and metaheuristic algorithm in order to solve more complicated problems, since Gams software has a limitation on the number of constraint and variables.

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