Operator assignment model for minimizing total operator cost in a flexible flow shop environment

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Abstract. This research proposes a mix-integer linear programming model for operator assignment in a flexible flow shop environment. The objective is to minimize the total cost of operator transportation and operator exchange between machine. The model was developed considering practical constrain whereas machine are operated semi automatically, allowing an operator to be assigned to more than one machine in a certain period of time. Therefore, number of operator could be less than the number of machine. The proposed model result in a reduction up to 60% for operator transportation and operator exchange compared to current practice. Current output of proposed model will assign operator based on the number of available operator. Further research will be conducted by relaxing the number of operator to increase the operator utilization.

1. Introduction
This paper arises from a practical case study of a textile industry. One of the textile process is creating a yarn by twisting together of fibers, also known as spinning process. The spinning process is categorized as a flexible flow shop system, which different type of yarn will go through the same stage of machine sequences. In each machine stage there are one or identical parallel machines. Different types of yarn are produced depending on the textile job order and due date. Thus, sequencing of yarn jobs is necessary to fulfill a certain objective. There are studies for job sequencing in a flexible flow shop [1]. In this case study, each machine has different level of automation, thus requiring less of operator time than the process time of the machine. In other words, it is possible that the operator shifts from one machine to another and conduct different jobs. Consequently, the number of operator could be less than the number of machines. Most research on operator assignment consider the number of operator is fixed during a certain time bucket in a planning horizon [2].

This research focus on the operator assignment problem. The objective of the research is to minimize the total cost of traveling and number of operator exchange between assignment, as seen in Figure 1.

The paper will be divided into four sections. The following section will discuss the model development. Section 3 will describe the case study and merit of the proposed model. The last section will point out remarks and further research activity.
2. Model development

The case study has similar characteristics of the operator assignment problem in an assembly line system [3]. Each operator is assigned certain task within a certain planning horizon. Differences is that operator must move between stations [4]. Gebennini [5] has developed a model for assigning operators into a flexible manufacturing system. The objective function is to minimize operators’ walking time. Gebennini also assumes that an operator may not shift to other machine until the job is finished. Considering the practical fact that machine has certain level of automation, the proposed model will relax this assumption enabling operator to move to other machine within the same time bucket if it fulfill the operator capacity within the time bucket. The proposed model will also consider a practical constrain for minimizing operator exchange. The objective function of case study is to minimize operator transportation time and operator switching between assignments.

The proposed model assumes that that the distance between station is linier in a flow shop layout [6]. The operator origin point will be set at the medium point between the closest and furthest assigned station. The operator skill level and walking speed are assumed the same.

2.1. Notation

The following notation of the proposed model.

Indexes
- $j = 1, ..., J$: station index;
- $k = 1, ..., K$: operator index;
- $t = 1, ..., T$: time buckets in the planning horizons;

Parameters
- $C_i$: traveling cost
\( C_2 \): operator exchange cost  
\( \tau \): time bucket length  
\( T^{\text{man}} \): operator’s available time  
\( \beta_{jt} \): amount of time for each operator required at station \( j \) during time \( t \)  
\( f_{jt} \): frequency of operator on station \( j \) during time bucket \( t \).  
\( \beta_{jt} \): binary parameter set to 1 if station \( j \) is working a job in time bucket \( t \); 0 otherwise  
\( d_j \): walking distance of station \( j \) from the origin point

**Decision variables**

- \( x_{jkt} \): binary value set to 1 if operator \( k \) is assigned to station \( j \) in time bucket \( t \), 0 otherwise  
- \( y_{jkt} \): binary value set to 1 if station \( j \) is the furthest station served by operator \( k \) in time bucket \( t \)  
- \( z_{jkt} \): binary value set to 1 if station \( j \) is the closest station served by operator \( k \) in time bucket \( t \)  
- \( d_{jkt} \): walking distance of station \( j \) assigned to operator \( k \) from the medium point of the operator \( k \)

### 2.2. Model formulation

The proposed mixed-integer linear model is formulated as follows:

\[
\begin{align*}
\min & \quad C_1 \sum_{j=1}^{J} \sum_{k=1}^{K} x_{jkt} + C_2 \sum_{j=1}^{J} \sum_{k=1}^{K} \sum_{t=1}^{T} d_{jkt} f_{jt} \\
\text{Subject to} & \quad \sum_{k=1}^{K} x_{jkt} = \beta_{jt}, \quad \forall j, \forall t \quad (2) \\
& \quad y_{jkt} \geq x_{jkt} - \sum_{h=1}^{J} x_{hkt}, \quad \forall j < J, \forall k, \forall t \quad (3) \\
& \quad y_{jkt} = x_{jkt}, \quad \forall k, \forall t \quad (4) \\
& \quad \sum_{j=1}^{J} y_{jkt} \leq 1, \quad \forall k, \forall t \quad (5) \\
& \quad z_{jkt} = x_{1kt}, \quad \forall k, \forall t \quad (6) \\
& \quad z_{jkt} \geq x_{jkt} - \sum_{h=1}^{J} x_{hkt}, \quad \forall j > 1, \forall k, \forall t \quad (7) \\
& \quad \sum_{j=1}^{J} z_{jkt} \leq 1, \quad \forall k, \forall t \quad (8) \\
& \quad \bar{d}_{jkt} = \frac{1}{2} \left( \sum_{i=1}^{J} d_{i,y_{ikt}} + \sum_{i=1}^{J} d_{i,z_{ikt}} \right) - d_{jx_{jkt}} - M(1 - x_{jkt}), \quad \forall j, \forall k, \forall t \quad (9) \\
& \quad \bar{d}_{jkt} = d_{jx_{jkt}} - \frac{1}{2} \left( \sum_{i=1}^{J} d_{i,y_{ikt}} + \sum_{i=1}^{J} d_{i,z_{ikt}} \right), \quad \forall j, \forall k, \forall t \quad (10) \\
& \quad \bar{b}_{jkt} = \frac{1}{2} \sum_{i=1}^{J} d_{i,y_{ikt}} - \sum_{i=1}^{J} d_{i,z_{ikt}} - d_{jx_{jkt}} - M(1 - x_{jkt}), \quad \forall j, \forall k, \forall t \quad (11) \\
& \quad \bar{b}_{jkt} = \frac{1}{2} \sum_{i=1}^{J} d_{i,y_{ikt}} + \sum_{i=1}^{J} d_{i,z_{ikt}}, \quad \forall j, \forall k, \forall t \quad (12) \\
& \quad \sum_{j=1}^{J} \bar{d}_{jkt} f_{jt} + \sum_{j=1}^{J} \bar{b}_{jkt} f_{jt} \leq T^{\text{man}}, \quad \forall k, \forall t \quad (13) \\
& \quad \bar{d}_{jkt} \geq 0, \quad \forall j, \forall k, \forall t \quad (14) \\
& \quad \bar{b}_{jkt} \geq 0, \quad \forall j, \forall k, \forall t \quad (15) \\
& \quad x_{jkt}, y_{jkt}, z_{jkt} \in [0,1], \quad \forall j, \forall k, \forall t \quad (16)
\end{align*}
\]

Where

- Constraint (2) assure that an operator could be assigned at one machine in a certain time;  
- Constraints (3)-(5) identifies the last station assign to each operator in each time bucket;  
- Constraints (7)-(8) identifies the first station assign to each operator in each time bucket;  
- Constraints (9)-(10) calculate the of the operator medium point between station \( j \) assigned to operator \( k \) in time bucket \( t \);  
- Constraint (11)-(12) is the binary setting to identify in number of operator exchange;  
- Constraint (13) is the capacity for each operator for traveling time and assignment time at station \( j \) in time bucket \( t \);
Cons (14)-(16) define non-negative and binary variables.

3. Case study
The case study is undertaken in a textile company, specifically in the spinning department. The spinning department has six stages process: open bale, blowing, carding, drawing breaker, drawing finisher and open-end. There are two set of drawing breaker, three set of drawing finisher and three set of open-end. The current distance between station is shown in Table 1. The traveling time given are the standard traveling time measured from different operator.

Table 1. Traveling time

| From          | To Station | Time (minutes) |
|---------------|------------|----------------|
| 1, Open bale  | 0,09       |                |
| 2, Blowing    | 1,60       |                |
| 3, Drawing breaker 1 | 2,20      |                |
| 4, Drawing breaker 2 | 2,44      |                |
| 5, Drawing finisher 1 | 2,80      |                |
| 6, Drawing finisher 2 | 3,07      |                |
| 7, Drawing finisher 3 | 3,16      |                |
| 8, Open end 1 | 3,42       |                |
| 9, Open end 2 | 3,74       |                |
| 10, Open end 3 | 3,86       |                |
| 11, Open end 4 | 3,97       |                |

The company is currently practicing a job sequencing algorithm to minimize lateness. The job sequence is then transformed into the operator load to conduct the job sequencing as shown in Table 2. Note that the Table 2 does not directly inform the job sequence but depicts the necessary workload to operate the job. The workload given in are standard time for operating the machine induced by the job sequencing. Currently the time bucket is set to 30 minutes and operator time break is set at 8 and 0, where no job are assigned.

Table 2. Production schedule

| Time Bucket | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|-------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|
| 1           | 30.00 | 30.00 | 9.99 | 10.48 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2           | 0.00 | 10.71 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 10.71 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 10.71 |
| 3           | 29.87 | 17.20 | 15.91 | 1.81 | 15.91 | 1.81 | 15.91 | 0.00 | 0.00 | 15.91 | 17.20 | 15.91 | 15.91 | 15.91 | 15.91 |
| 4           | 15.74 | 17.70 | 7.90 | 11.28 | 7.90 | 17.70 | 7.80 | 0.00 | 0.00 | 14.72 | 17.80 | 7.80 | 12.56 | 16.72 | 7.80 | 9.90 |
| 5           | 9.90 | 5.54 | 13.74 | 17.60 | 7.90 | 10.46 | 18.72 | 0.00 | 0.00 | 7.80 | 7.80 | 21.48 | 7.80 | 7.80 | 17.80 | 13.58 |
| 6           | 25.96 | 14.30 | 16.10 | 11.96 | 27.32 | 15.74 | 11.10 | 0.00 | 0.00 | 15.52 | 27.32 | 15.52 | 13.76 | 11.86 | 22.54 | 19.74 |
| 7           | 17.08 | 26.64 | 11.42 | 14.42 | 18.42 | 21.86 | 17.42 | 0.00 | 0.00 | 15.52 | 12.54 | 25.52 | 17.32 | 15.52 | 13.76 | 25.86 |
| 8           | 18.30 | 15.52 | 23.76 | 14.52 | 9.88 | 13.30 | 28.32 | 0.00 | 0.00 | 18.74 | 12.54 | 10.64 | 23.76 | 15.52 | 17.32 | 28.74 |
| 9           | 8.57 | 6.54 | 2.08 | 6.56 | 2.50 | 6.95 | 2.50 | 0.00 | 0.00 | 5.73 | 2.50 | 6.95 | 3.33 | 4.48 | 2.91 | 6.95 |
| 10          | 6.90 | 7.37 | 2.50 | 5.31 | 2.91 | 7.79 | 2.50 | 0.00 | 0.00 | 5.73 | 7.37 | 2.50 | 5.73 | 7.79 | 1.25 |
| 11          | 8.55 | 2.50 | 6.56 | 2.08 | 6.54 | 4.89 | 2.91 | 0.00 | 0.00 | 2.91 | 6.14 | 5.29 | 3.33 | 5.73 | 2.50 | 7.37 |

The current operator assignment of the company is depicted in Figure 2. The operator assignment is based on trial and error conducted by the supervisor and being refined from time to time.
The proposed model has been solved using Ilog Cplex™. The optimal solution is depicted in Figure 3. Seven operators have been assigned. The total transportation is reduced from 636 meters to 204 meters and there is less operator exchange between station. Allocation of operator assignment is currently proportional to the workload, where only 1 operator is need for station 9, 10 and 11. The supervisor verify the feasibility of only allocating 1 operator for machine 9, 10 and 11. In addition, station 4, 5, 6 dan 7, which previously was relocated an additional of two operators. The above facts were confirmed at site where as many work-in-processes was queueing for operator to setup.

4. Conclusions and further research
This paper proposes a mixed integer linier model for operator assignment in a flexible flow shop environment. The model minimizes the total operator assignment cost consisting of traveling cost and operator exchange cost. Practical constrain has been considered and a case study has been presented. Further development of the model will relax the number of operator available to increase operator utilization.

References
[1] Silva C, Reis V, Morais A, Brilenkov I, Vaza J, Pinheiro T, Neves M, Henriques M, Varela M L, Pereira G, Dias L, Pernandes N O and Carmo-Silva S 2017 A comparison of production
control systems in a flexible flow shop Procedia manufacturing 13 1090-95.
[2] Ernst A, Jiang H, Krishanamoorthy M and Sier D 2004 Staff scheduling and rostering; a review of application, methods and models European journal of operational research 153 3-27.
Van den Berg J, Belien J, De Bruecker P, Demeulemeester E and De Boeck L 2013 Personal scheduling: a literature review European journal of operational research 226(1) 367-85
[3] Sungur B and Yavuz Y 2006 Assembly line balancing with hierarchical worker assignment Journal of Manufacturing Systems, 37 290-98.
[4] Eiselt H A and Maianov V 2018 Empolyee positioning and workload allocation Computer & operations research 35(2), 513-24
[5] Geneninni E, Zeppetella L, Grassi A and Rimini B 2016 Minimizing operators’ walking times into a linear system layout IFAC 49-12 1709-14.
[6] Heragu S S 2016 Facilities design CRC Press p 128