Special workers’ assignment optimization under
the limited-cycled model with multiple periods

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Abstract

Although assembly line is widely used for several decades since it appears during the Industrial Revolution, nowadays, it still has the vitality, especially in the developing countries such as China, where labor-intensive enterprise is still the mainstay industry. Assembly line has its advantages for reducing costs and production time. However, laborer is the main factor of production speed in such a labor-intensive enterprise. Because of the various working capacity of worker, one work process may delay or idle, and this will influence processes. This unforeseeable consecutive delay of process may lead to the postponing of whole manufacturing production. In order to minimize the risk, the assignment of the workers, especially untrained worker is focused on. In previous researches, rules of optimal worker assignment with two kinds of workers, which are distinguished by the capacity of processing, were proposed when minor untrained workers are less than four people. In this paper, we deal with the rules under this LCMwMP (limited-cycled model with multiple periods) model without concerning the number of minor untrained workers. Additionally, some rules of minor well-trained workers assignment optimization are researched by numerical analyses.

Key words: Optimization technique, Production line, Work management, Labor-intensive enterprise, Production scheduling, Multiple periods

1. Introduction

Even the assembly line has been widely used for several decades, we can still benefit from it for reducing processing costs and production time. However, no matter how increased the reliability of the machine on the assembly line is by the developing of technology, human error of the worker, appearing as mistake or failure, is inescapable. It will lead to a delay of whole production processes. Because of the variability of ability of workers, the time of the same processing is different from people to people. In particular, the new recruit is not skillful, so they are considered with a higher probability of delay. As a result, there is no important thing than arranging these new recruits, which is called as untrained-workers in the essay.

The first mathematical formalization of assembly line balancing is established by Salveson (1955) 60 years ago, and during assembly line balancing problem develops, Yamamoto et al. (2006) produce the limit-cycle model with multiple periods (LCMwMP). This model is set with constraint condition (e.g., processing time with a target), which is repeated in every multiple periods. If the constraint condition is broken through, an expected risk (e.g., penalty cost) will be incurred.

Numerous manufacturing organizations generate and update production schedules, which are plans that state when certain controllable activities (e.g., processing of jobs by resources) should commence. Production schedules
coordinate activities to increase productivity and minimize processing costs. A production schedule can identify resource conflicts, control the release of jobs to the shop, ensure that raw materials are ordered in time, determine whether delivery promises can be met, and identify time periods available for preventive maintenance.

Priorities and capacity are prominent keywords in production scheduling (Herrmann 2007). The former concerns what should be done first and the latter concerns by whom should it be done. Wight (1984) defines scheduling as “establishing the timing for performing a task” and observes that in manufacturing firms, there are multiple types of scheduling, including the detailed scheduling of a shop order that indicates when each operation must start and end. Detailed scheduling has been defined as “the actual assignment of starting and/or completion dates to operations or groups of operations to show when these must be done if the manufacturing order is to be completed on time” (Cox et al. 1992). They note that this is also known as operations scheduling, order scheduling, and shop scheduling.

Over the decades, many attempts have been made to address the problem of scheduling in flow shops. The most common objective of scheduling is the minimization of the makespan. Some important studies on flow shop scheduling with the makespan objective were conducted by Johnson (1954), Ignall and Schrage (1965), Campbell et al. (1970), Dannenbring (1977), Nawaz et al. (1983), Widmer and Hertz (1989), Taillard (1990), Ogbu and Smith (1990), Ishibuchi et al. (1995), and Framanan et al. (2003). Since a vast majority of flow shop scheduling problems are NP-complete in nature, many researchers have focused their efforts on the development of heuristics that yield optimal or near-optimal solutions for large-scale problems. Another important objective of scheduling is the minimization of the total flow time (or the sum of job completion times) that results in minimum in-process inventory, and heuristics with this objective have been developed by Miyazaki et al. (1978), Gelders and Sambandam (1978), Rajendran (1993), Ho (1995), Rajendran and Ziegler (1997), Liu and Reeves (2001), and Rajendran and Ziegler (2004). Another objective of significance is the minimization of the total job tardiness, and there have been some attempts to develop efficient heuristics (Gelders and Sambandam 1978, Kim 1993, Parthasarathy and Rajendran 1998, Hasija and Rajendran 2004).

Depending whether the constraint condition (target processing time) is reset or not, the LCMwMP is divided into reset model and non-reset model. In the field of reset model, a recursive formula for the total expected risk and an algorithm for optimal assignments based on the branch and bound method are proposed by Yamamoto et al. (2007).

Recently, Yamamoto et al. (2011) and Kong et al. (2010) proposed properties of optimal worker assignment with two kinds of workers in which one special worker exists. Then, Kong et al. (2011a, 2011b) proposed rules of optimal worker assignment with two special workers when special workers are less than 3.

In this paper, based on the researches above, especially according to the rules which is found by Song et al. (2014), we try to expand the rules without the limit of numbers of special workers. It is to say, in this paper, if the untrained worker is minority, no matter the number of untrained workers, it still has the same properties as the rules in Song et al. (2014). On the other hand, if the well-trained worker is minority, similar rules no matter the number of well-trained workers are researched by numerical analyses. This paper is written as the following prescribed order. First, reset model as a simple model of LCMwMP is introduced. Then, the rules of optimal assignment are demonstrated by derivation. Finally, the assignment optimization rules about minority untrained or well-trained workers are discussed by numerical analyses.

2. Model explanation

In this section, we consider a ‘Reset model’ which is a simple model of the LCMwMP. Then, we define the optimal assignment problem in reset model.

2.1 Reset model of LCMwMP

The model is considered based on the following definitions by Kong et al. (2010) in Figure 1:

(1) In an assembly line system, $n$ is the number of processes. The production (we call it job in the following article) is processed in a rotation of process 1, process 2, ..., and process $n$. One production will be processed by all $n$ processes.

(2) $Z$ is the cycle time of all of the processes, which can be also considered as target processing time. All of the jobs should be accomplished in current process and moved to next process by time $Z$. 
(3) Because of the various processing abilities of workers, the actual processing time cannot always obey the limit of target processing time \( T_s \). Idle and delay should also be concerned in this model. For \( 1 \leq w \leq n \), processing time of process \( w \) is donated by \( T_w \).

In this model, a regular processing cost \( C_s (> 0) \) per unit time will permanently occur during target processing time \( T_s \), regardless whether it is idle or delay. It is for the reason that although the job is accomplished prematurely in current process, the next process may be occupied by another job. The job must wait for its start. As a result, an idle cost per unit time, \( C_s (\geq 0) \), arises. On the other hand, if the processing time is greater than \( T_s \), it is supposed that the delay of process time can be recovered by the overtime works or spare workers in this process, and as a result overtime works or additional resources will be requested in order to meet the target time \( T_s \). Thus, a delay cost per unit time, \( C_s (\geq 0) \), arises (that is why we call the model a ‘Reset Model’).

In summary of above, we obtain the following:

(4) The processing cost per unit time, \( C_j (> 0) \), for the target processing time limit occurs in each process.

(5) When \( T_w \leq T_s \), the idle cost per unit time, \( C_s (\geq 0) \), occurs.

(6) When \( T_w > T_s \), the delay cost per unit time, \( C_s (\geq 0) \), occurs in the process if delay occurs in consecutive \( i \) processes before its process, for \( i = 1, 2, ..., n \). If the delay continues for several processes, it can be considered that it will cost more for recover the delay. It is supposed that \( C_s (\geq 0) \) is increasing in \( i \), which can be expressed as \( 0 < C_s (1) < C_s (2) < ... < C_s (n) \).

2.2 The assumption of processing abilities of workers

The aim of this paper is to search the optimal assignment of workers when special worker (untrained or well-trained worker(s)) number is fewer than half of all workers) exists, so the reasonable assumption of the property of worker is particularly important. The assumption is the followings.

(1) Only one worker can be assigned to each process. Each process must be assigned with one worker.

(2) The processing time of workers is self-dependent. The processing ability is decided by the property of worker own and is not influenced from the processing status such as idle or delay.

(3) In this paper, the workers are distinguished into two types of workers by the processing ability, marking as \( A \) and \( B \). Although the processing abilities are various from each other, it is difficult to calculate the optimal assignment and explain the rules clearly and briefly without using such marks. Worker \( A \) represents for untrained worker whose processing ability is lower than others, and \( B \) represents regular worker. The number of \( A \) is less than that of \( B \), because the untrained worker (it can also be considered as new recruits) is always minority in the real factory.

(4) These two kinds of workers have different probability of idle or delay. If the processing time of worker is marked as \( T_l \), where \( l \in \{ A, B \} \),

\[
P_l \; : \; \text{The probability of worker } l \text{ becoming idle, which is } \Pr\{ T_l \leq Z \},
\]

\[
Q_l \; : \; \text{The probability of the worker } l \text{ becoming delayed, which is } \Pr\{ T_l > Z \},
\]

\[
T_{sl} \; : \; \text{The expected idle time of the worker } l \text{, which is } \mathbb{E}[Z - T_l] \Pr\{ T_l \leq Z \},
\]

\[
T_{ld} \; : \; \text{The expected delay time of the worker } l \text{, which is } \mathbb{E}[T_l - Z] \Pr\{ T_l > Z \},
\]

where \( l(O) \) is an index function and given as follows:

\[
l(O) = \begin{cases} 
1 & (O \text{ is true}) \\
0 & (O \text{ is not true}). 
\end{cases}
\]

2.3 Optimal assignment problem under reset model

We consider that \( m+1 \) untrained workers are allocated in \( n \) processes in this reset model. Because of untrained workers are minority, so \( m + 1 < n/2 \). One of the most important problems is how to allocate workers to processes for minimizing the expected cost. We call such a problem the optimal assignment problem. For describing the optimal assignment problem, we define the following notations:

For \( 1 \leq i < j_1 < j_2 < ... < j_m \leq n \),

\[
\pi(i, j_1, ..., j_m) : m+1 \text{ numbers of untrained workers are assigned to process } i, j_1, ..., j_m, \text{ and the other } n-m-1 \text{ regular workers are assigned to the other processes}.
\]
Process

Fig. 1 Description of idle and delay cost in reset model of LCMwMP

\( TC(n; \pi(i, j_1, \ldots, j_m)) : \) The total costs of processes 1 to \( n \) when workers are allocated by assignment \( \pi(i, j_1, \ldots, j_m) \) which can be expressed as

\[
TC(n; \pi(i, j_1, \ldots, j_m)) = nC_rZ + f(n; \pi(i, j_1, \ldots, j_m))
\]  

(1)

where,

\( f(n; \pi(i, j_1, \ldots, j_m)) : \) The sum of the expected idle cost and the expected delay cost caused in process \( n \).

By using these notations, the optimal assignment problem with multiple periods becomes the problem of obtaining assignment in the following equation:

\[
TC(n; \pi^*) = \min_{1 \leq i < j_1 < \cdots < j_m \leq n} TC(n; \pi(i, j_1, \ldots, j_m))
\]  

(2)

In this paper, we call \( \pi^* \) the optimal assignment.

However, it is easily known from (1) that if the target processing time \( Z \) is constant, the target production cost, \( nC_rZ \), is also constant, so we can simplify (2) to

\[
f(n; \pi^*) = \min_{1 \leq i < j_1 < \cdots < j_m \leq n} f(n; \pi(i, j_1, \ldots, j_m))
\]  

(3)

3. Rule of optimal assignment of minor untrained workers

In this section, we consider the situation that the processing time of \( n-m-1 \) regular workers, which can be marked as \( B \), follow the same distribution and the other \( m+1 \) untrained workers, which can be marked as \( A \), follow a different distribution from regular workers \( B \) (Yamamoto et al., 2011).

It is demonstrated that it is optimum when and only when the first process is arranged with untrained worker. It can be summarized as the following Theorem.

Theorem.

When \( C_p^{(i)} \) is increasing in \( i \), if \( Q_A > Q_B \), \( TL_A > TL_B \), then \( \pi(1, j_1, j_2, \ldots, j_m) \) is the optimal assignment, where \( j_1, j_2, \ldots, j_m \) is not involved.

Proof.

Here we set a function \( D(i) \) to evaluate the value fluctuation of expected total cost when shift the allocation of the first untrained worker to one process next, which means

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Fig. 2  The change of expected cost when shifting the first untrained worker from allocation 1 to \(n-2\)

\[
D(i) = \text{TC}(n; \pi(i + 1, j_1, ..., j_m)) - \text{TC}(n; \pi(i, j_1, ..., j_m))
\]

(4)

By the definition of \(\text{TC}(n; \pi(i, j_1, ..., j_m))\) (Song et al. 2014), we can gain that

\[
D(i) > \overline{D}(i) = \sum_{\alpha=1}^{n-1-1} \left( C_p^{(\alpha+1)} - C_p^{(\alpha)} \right) TL_B Q_B^{\alpha-1} (Q_A - Q_B) - \sum_{\alpha=1}^{i} \left( C_p^{(\alpha+1)} - C_p^{(\alpha)} \right) TL_B Q_B^{\alpha-1} (Q_A - Q_B)
\]

(5)

For \(n-i-1 > i\), that is \(i < \frac{n-1}{2}\), and \(Q_A > Q_B\), \(\overline{D}(i) > 0\)

which means the expected cost increases with shifting first untrained worker from assignment \(i\) to \(i+1\).

In contrast, for \(i > \frac{n-1}{2}\), and \(Q_A > Q_B\), \(\overline{D}(i) < 0\).

According to Song et al. (2014), \(D(i) > \overline{D}(i)\). because that untrained worker \(A\) has a bad performance of process speed than \(B\), it is obviously valid that \(TL_A > TL_B\) and \(Q_A > Q_B\), then replacing \(TL_B\) and \(Q_B\) instead of \(TL_A\) and \(Q_A\). We can’t say \(D(i) < 0\), for \(\overline{D}(i) < 0\). Whether the expected cost is decreasing or increasing is no clear (shown as Figure 2).

The difference of expected cost between \(\text{TC}(n; \pi(1, j, k))\) and \(\text{TC}(n; \pi(n-2, j, k))\) is

\[
\sum_{i=1}^{n-3} D(i)
\]

\[
\sum_{i=1}^{n-3} D(i) = \sum_{i=1}^{n-3} \left( \sum_{\alpha=1}^{n-1-1} \left( C_p^{(\alpha+1)} - C_p^{(\alpha)} \right) TL_B Q_B^{\alpha-1} (Q_A - Q_B) - \sum_{\alpha=1}^{i} \left( C_p^{(\alpha+1)} - C_p^{(\alpha)} \right) TL_B Q_B^{\alpha-1} (Q_A - Q_B) \right)
\]

(6)

\[
= \sum_{\alpha=2}^{n-2} \left( C_p^{(\alpha+1)} - C_p^{(\alpha)} \right) TL_B Q_B^{\alpha-1} (Q_A - Q_B) > 0
\]

From Eq. (6),

\[
\sum_{i=1}^{n-3} D(i) > \sum_{i=1}^{n-3} \overline{D}(i) > 0
\]

(7)
holds.

When shifting the allocation of first untrained worker from process 1 to \( n-m \), the expected cost transit as Figure 2.

In summary, for \( 1<i<n-m \), from Eq. (7),

\[
TC(n; i(1, j, k)) < TC(n; i(1, j, k))
\]

holds.

Then the Theorem is proved.

4. Numerical experiment

Although the theorem mentioned above is always holding no matter which distribution the processing time follows, we should assume a certain distribution when we try to demonstrate it by numerical experiment. It is assumed that the processing time of these two kinds of workers follows Erlang distribution. In other word, \( Q \), the probability of the worker \( l \) becoming delayed is

\[
Q_l = \sum_{k=0}^{m-1} \frac{(\mu_l Z)^k}{k!} e^{-\mu_l Z}
\]

where \( l \in \{A, B\} \).

(1) Untrained worker is \( A \) and regular worker is \( B \).

(2) \( \mu_l \) is the processing speed parameter. When \( \mu_l \) is bigger, it means processing speed is higher and lower possibility of delay of processing.

(3) \( m \) is the shape parameter. As mentioned in the introduction above, \( m \) can be considered as the quantity of tasks in one process. If the shape parameter \( m=1 \), Erlang distribution simplifies to the exponential distribution.

(4) \( Z \) is target processing time, which is mentioned in the model explanation.

Other parameters are assumed as follows,

Consecutive Delay Cost \( C_p^{(k)} \):

- \( C_p^{(1)} = 40 \), \( C_p^{(2)} = 80 \), \( C_p^{(3)} = 160 \), \( C_p^{(4)} = 320 \), \( C_p^{(5)} = 640 \), \( C_p^{(6)} = 1280 \)
- \( C_p^{(7)} = 2560 \), \( C_p^{(9)} = 5120 \), \( C_p^{(10)} = 10240 \), \( C_p^{(20)} = 20480 \)

Processes \( n = 7, 9, 10 \);

Target Processing Time \( Z = 2 \);

Idle Cost \( C_S = 20 \).

Based on the above parameters, the total expected cost \( TL \) can be calculated by the method proposed by Yamamoto et al. (2007).

| \( n=7 \) | \( \mu_A = 0.1, \mu_B = 0.2 \) | \( \mu_A = 0.1, \mu_B = 0.4 \) | \( \mu_A = 0.1, \mu_B = 0.6 \) | \( \mu_A = 0.1, \mu_B = 0.8 \) | \( \mu_A = 0.1, \mu_B = 1.0 \) |
|----------------|----------------|----------------|----------------|----------------|----------------|
| ABBBBBAAB | 9432.32 | 3664.05 | 2273.77 | 1847.52 | 1686.23 |
| BABBAAA | 9933.29 | 4050.90 | 2474.11 | 1950.21 | 1742.80 |
| BBABBBAA | 10037.52 | 4422.67 | 2692.10 | 2062.95 | 1797.84 |
| BBBBABA | 10679.98 | 4783.62 | 2984.95 | 2285.01 | 1959.53 |
| BBBBBAA | 10990.31 | 5137.87 | 3429.51 | 2811.85 | 2545.63 |
Table 2. The comparison when the number of untrained worker is different (n=9)

| $\mu_A$ | $\mu_B$ | 1 untrained | 2 untrained | 3 untrained | 4 untrained |
|---------|---------|-------------|-------------|-------------|-------------|
| 0.1     | 0.2     | ABBBBBBBB   | AABBBBBBBB  | AAABBBBBB   | AAABBBBBBA |
| 0.1     | 0.3     | ABBBBBBB   | AABBBBBBB   | AAABBBBBB   | AAABBBBBBA |
| 0.1     | 0.4     | ABBBBBBB   | AABBBBBBB   | AAABBBBBB   | AAABBBBBBA |
| 0.1     | 0.5     | ABBBBBBB   | AABBBBBBB   | AAABBBBBB   | ABABBABBA  |
| 0.1     | 0.6     | ABBBBBBB   | AABBBBBBB   | AAABBBBBB   | ABABBABBA  |
| 0.1     | 0.7     | ABBBBBBB   | ABBBBBBB    | ABBABBBA    | ABABBABBA  |
| 0.1     | 0.8     | ABBBBBBB   | ABBBBBBB    | ABBBBBBB    | ABABBABBA  |
| 0.1     | 0.9     | ABBBBBBB   | ABBBBBBB    | ABBBBBBB    | ABABBABBA  |
| 0.1     | 1.0     | ABBBBBBB   | ABBBBBBB    | ABBBBBBB    | ABABBABBA  |

4.1 Variation trend of expected cost by shifting the allocation of the first untrained workers

In Table 1, it shows the variation trend of total expected cost by shifting the assignment of the first untrained worker. It can be known that no matter how is the disparity between the processing speeds of these two kinds of worker, the expected cost always reaches lowest when 1 untrained worker is assigned to the first process.

Here we also find that with shifting the allocation of first untrained worker behind, the expected cost is monotonic increasing.

4.2 Comparison by different number of untrained worker

In Table 2, when processes number is $n=9$, it shows the optimal assignment under different situation. We assume $\mu_A$ as a fixed value, and change the number of untrained workers from 1 to 4, and the processing speed parameter of worker $B$ from 0.2 to 1.0. However, the all optimal assignment shows that it must arrange untrained worker to the first process. In another word, no matter how the number of untrained worker is, the rule mentioned above always holds.

4.3 Comparison by different number of well-trained worker

The goal of research is not only conducting numeral experiment, but also summarizing the common rules of optimal assignment from the results of experiments. We may find and conclude some rules if we compare the results with previous researches. In Table 3, it compares the experiment result when 3 well-trained workers exist and the results when 1, 2 or 3 well-trained worker(s) exist(s) which is discussed in Kong et al. (2011a). The process number is all set to $n=10$, and the processing rate of worker $A$ is set to 0.1 and that of $B$ is set from 0.2 to 1.0.

We can find that, when both of well-trained and untrained workers have bad processing speed, all well-trained would be arranged at the end of all processes. When the disparity of speed increases, these well-trained workers may gradually move forward together, and finally separate untrained-workers $A$ into several parts as an assignment …$B…B…B…$.

In future research, we will try to certificate the rules with mathematical demonstration.
5. Conclusion

In this paper, we considered the properties of optimal assignment with special (untrained or well-trained) workers in LCMwMP. First, we systematically classified and modeled the multi-period problem and defined the optimal workers assignment problem under the reset model. Secondly, by the mathematical demonstrate, we know that it is optimum when and only when the first process is arranged with untrained worker. Finally, some rules of minority well-trained workers’ assignment optimization are researched by numerical analyses. We certificate the assumptions and propose the rules which we found in the results of experiment as follow.

1. If both of $\mu_A$ and $\mu_B$ is small, it showed the result that all the minority well-trained workers should be arranged at the last processes. It is to say, $\pi(\frac{n}{2}+1,\ldots,n-2,n-1,n)$ is the optimal assignment.

2. When the disparity becomes bigger, it is optimal that minority well-trained workers move forward together. This type can be expressed as $\pi(i,i+1,i+2,\ldots,i+\frac{n}{2}-1)$, when $i+\frac{n}{2}-1<n$.

As a future research, we still want to try to find out if the rules, which are demonstrated by the case with one, two or three untrained workers in the previous researches, still holds when the number of untrained workers increases. We will try to demonstrate these rules and propose rules commonly applying to all cases without concerning the number of well-trained workers and whether well-trained workers are minority or not.

References

Campbell, H.G., Dudek, R.A. and Smith, M.L. (1970) A heuristic algorithm for the n-job, m-machine sequencing problem, Management Science, Vol. 16, No. 10, pp.B630–B637.

Cox, J.F., Blackston Jr., J.H. and Spencer, M.S. (Eds.) (1992) APICS Dictionary, American Production and Inventory Control Society, Falls Church, Virginia.

Dannenbring, D.G. (1977) An evaluation of flow-shop sequencing heuristics, Management Science, Vol. 23, No. 11, pp.1174–1182.

Framinan, J.M., Leisten, R. and Rajendran, C. (2003) Different initial sequences for the heuristic of Nawaz, Enscore and Ham to minimize makespan, idletime or flowtime in the static permutation flowshop, International Journal of Production Research, Vol. 41, No. 3, pp.121–148.

Gelders, L.F. and Sambandam, N. (1978) Four simple heuristics for scheduling a flow-shop, International Journal of Production Research, Vol. 16, No. 3, pp.211–231.

Hasija, S. and Rajendran, C. (2004) Scheduling in flowshops to minimize total tardiness of jobs, International Journal of Production Research, Vol. 42, No. 11, pp.2289–2301.

Herrmann, J.W. (2007) The Legacy of Taylor, Gant, and Johnson: How to Improve Production Scheduling, The Institute for Systems Research Technical Report, No. 26, pp.1–3.

Ho, J.C. (1995) Flowshop sequencing with mean flowtime objective, European Journal of Operational Research, Vol. 81, No. 3, pp.571–578.

Ignall, E. and Schrage, L. (1965) Application of the branch-and-bound technique to some flowshop scheduling problems, Operations Research, Vol. 13, No. 3, pp.400–412.
Ishibuchi, H., Misaki, S. and Tanaka, H. (1995) Modified simulated annealing algorithms for the flow shop sequencing problems, European Journal of Operational Research, Vol. 81, No. 2, pp.388–398.

Johnson, S.M. (1954) Optimal two- and three-stage production schedules with setup times included, Naval Research Logistics, Vol. 1, No. 1, pp.61–68.

Kim, Y.D. (1993) Heuristics for flowshop scheduling problems minimizing mean tardiness, Journal of Operational Research Society, Vol. 44, No. 1, pp.19–29.

Kong, X., Sun, J., Yamamoto, H. and Matsu, M. (2010) A study of an optimal arrangement of a processing system with two kinds of workers in a limited-cycle problem with multiple periods, Proceedings of the 11th Asia Pacific Industrial Engineering & Management Systems Conference (APIEMS2010), Melaka, Malaysia. (CD-ROM)

Kong, X., Sun, J., Yamamoto, H. and Matsu, M. (2011) Two special workers’ optimal assignment with two kinds of workers under a limited-cycle problem with multiple periods, Proceedings of the 21st International Conference of Production Research (ICPR2011), Stuttgart, Germany. (CD-ROM)

Kong, X., Sun, J., Yamamoto, H. and Matsu, M. (2011) Optimal worker assignment with two special workers in limited-cycle multiple periods, Proceedings of the Asian Conference of Management Science & Applications 2011 (ACMSA2011), Sanya, China. (CD-ROM)

Liu, J. and Reeves, C.R. (2001) Constructive and composite heuristic solutions to the $P/\Sigma C_i$ scheduling problem, European Journal of Operational Research, Vol. 132, No. 2, pp.439–452.

Miyazaki, S., Nishiyama, N. and Hashimoto, F. (1978) An adjacent pairwise approach to the mean flow-time-scheduling problem, Journal of the Operations Research Society of Japan, Vol. 21, No. 2, pp.287–299.

Nawaz, M., Enscore Jr., E.E. and Ham, I. (1983) A heuristic algorithm for the $m$-machine, $n$-job flowshop sequencing problem, OMEGA, Vol. 11, No. 1, pp.91–95.

Nils, B., Malte, F. and Armin, S. (2007) A classification of assembly line balancing problems, European Journal of Operational Research, Vol. 183, No. 2, pp.674–693.

Ogbu, F.A. and Smith, D.K. (1990) The application of the simulated annealing algorithm to the solution of the $n!/m!C_{max}$ flowshop problem, Computers & Operations Research, Vol. 17, No. 3, pp.243–253.

Parthasarathy, S. and Rajendran, C. (1998) Scheduling to minimize mean tardiness and weighted mean tardiness in flowshop and flowline-based manufacturing cell, Computers & Industrial Engineering, Vol. 34, No. 2, pp.531–546.

Rajendran, C. (1993) Heuristic algorithm for scheduling in a flowshop to minimize total flowtime, International Journal of Production Economics, Vol. 29, No. 1, pp.65–73.

Rajendran, C. and Ziegler, H. (1997) An efficient heuristic for scheduling in a flowshop to minimize total weighted flowtime of jobs, European Journal of Operational Research, Vol. 103, No. 1, pp.129–138.

Rajendran, C. and Ziegler, H. (2004) Ant colony algorithms for permutation flowshop scheduling to minimize makespan/total flowtime of jobs, European Journal of Operational Research, Vol. 155, No. 2, pp.426–438.

Salveson, M. E. (1995) The assembly line balancing problem, The Journal of Industrial Engineering, Vol. 6, No. 3, pp.18–25.

Song, P., Kong, X., Yamamoto, H., Sun, J. and Matsui, M. (2014) A study on rules of three untrained workers’ assignment optimization under the limited-cycled model with multiple periods, Proceedings of the 1st East Asia Workshop on Industrial Engineering, Hiroshima, Japan, November (on CD-ROM).

Taillard, E. (1990) Some efficient heuristic methods for the flowshop sequencing problem, European Journal of Operational Research, Vol. 47, No. 1, pp.65–79.

Widmer, M. and Hertz, A. (1989) A new heuristic method for the flowshop sequencing problem, European Journal of Operational Research, Vol. 41, No. 2, pp.186–193.

Wight, Q. W. (1984) Production and Inventory Management in the Computer Age, Van Nostrand Reinhold Company, Inc., New York.

Yamamoto, H., Matsui, M. and Bai, X. S. (2007) A branch and bound method for the optimal assignment during a Limit-cycle problem with multiple periods, Journal of Japan Industrial Management Association, Vol. 58, No. 1, pp.37–43.

Yamamoto, H., Matsui, M. and Liu, J. (2006) A basic study on a limited-cycle problem with multi periods and the optimal assignment problem, Journal of Japan Industrial Management Association, Vol. 57, No. 1, pp.23–31.

Yamamoto, H., Sun, J., Matsui, M. and Kong, X. (2011) A study of the optimal arrangement in the reset limited-cycle problem with multiple periods: with fewer special workers, Journal of Japan Industrial Management Association, Vol. 62, No. 5, pp.239–246.