# A MODIFIED GIFFLER AND THOMPSON ALGORITHM COMBINED WITH DYNAMIC SLACK TIME FOR SOLVING DYNAMIC SCHEDULE PROBLEMS

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**ABSTRACT**

A Modified Giffler and Thompson algorithm combined with dynamic slack time is used to allocate machines resources in dynamic nature. It was compared with a Real Time Order Promising (RTP) algorithm. The performance of modified Giffler and Thompson and RTP algorithms are measured by mean tardiness. The result shows that modified Giffler and Thompson algorithm combined with dynamic slack time provides significantly better result compared with RTP algorithm in terms of mean tardiness.

**Keywords:** modified Giffler and Thompson algorithm, dynamic slack time, real time order promising algorithm

## 1. INTRODUCTION

Giffler and Thompson (1960) developed the algorithms to solve job shop scheduling problems by minimizing the length of production schedules. The algorithms generate schedules of a partial subset of all possible schedules without delaying some other operation or violating the technological constraints, called the active schedules. A subset of the optimal schedules is contained in this subset. The active schedules of Giffler and Thompson are modified in order to produces non-delay schedules. The non-delay schedule is the schedule that no machine is kept idle when it could start processing some operation. In a subset, sometimes there is more than one possible operation that causes the conflict set. Dispatching rules are the methods to select an operation from the conflict set.

Many researches proposed heuristic schedule generation approaches by modifying the Giffler and Thompson algorithm and combine with dispatching rules. Sarli (2001) studied and modified Giffler and Thompson algorithm with shortest processing time (SPT), most work remaining (MWKR), earliest due date (EDD), flow due date (FDD), critical ratio (CR) and the job with the minimum index. The study compared the modified Giffler and Thompson algorithm with the bi-directional approaches.

The objective of the shop scheduling problem is to control resources among demand, job due dates and shop floor capacity in order to maximizing the shop's efficiency and customer's satisfaction. The efficiency of the shop can be measured in terms of various measures of performance. While one alternative schedule gets a good result relating to a certain criterion, it may give poor results relating to another criterion. Therefore, a relative importance of the various criteria involved and the interrelation among the criteria should be known.

The criteria of the performance measure can be divided into criteria based upon completion times, due dates, the inventory and utilization costs. Maximum flow time and minimizing completion time are the category that based upon completion times. Criteria based upon due dates are mean lateness, the maximum lateness, the mean tardiness and the maximum tardiness.

## 2. SCHEDULING ALGORITHMS

General assumptions of scheduling algorithms are explained as follows: (1) No pre-emption, it means that the operation once started will be processed without interruption until completion, (2) Each job has *m* distinct operations, one on each machine, (3) No cancellation, each job should be processed to completion, (4) The processing times are independent, (5) The times to move jobs between machines are negligible, (6) There are parallel machines at each workstation, and (7) Machines never breakdown.

### 2.1 Real Time Order Promising (RTP) Algorithm

Moses et al (2002) proposed a method for real time approach for the promising of order due dates in job shop environment. The RTP method assumes that orders arrive dynamically one at a time and is considered as follows: (1) Dynamic time phased availability of resources that are required for each operation of the orders, (2) Individual order specific characteristics, and (3) Existing commitments to orders that arrived previously.

The order flow time based on conditions at the time of arrivals as: $Di = Ti + Fi + B$ where $F_i$ is the estimated flow time of order *i,* and $T_i$ is arriving time of order *i* at time *T* with slack time *B,* and $D_i$ is due date of order *i*.

Ball et al (2002) proposed a real time approach to estimate the flow time by determining the time when each individual operation *j* ($j = 1, 2, 3 \ldots \theta$) required fulfilling order *i* could be completed.

The estimated flow time is shown as follows:

$t_{i,1}^{min} \leftarrow Ti$
for all operations *j* do
$t_{i,j}^{*} \leftarrow RO(t_{i,j}^{min}, p_{i,j})$
$t_{i,j+1}^{min} \leftarrow t_{i,j}^{*}$
$Fi \leftarrow t_{i,\theta} - t_{i,j}^{min}$

where $t_{i,1}^{min}$ is the earliest feasible start time of operation *j* on order *i,* and $t_{i,j}^{*}$ is the estimated completion time of operation *j* on order *i,* and $p_{i,j}$ is the total set up and processing time for operation *j* on order *i*. Function *RO( )* is the earliest time when a resource will be available to complete the operation.

### 2.2 Modified Giffler and Thompson Algorithm Combined with Dynamic Slack Time

Giffler and Thompson(1960) developed a scheduling algorithm that solve problems to minimize the length of production schedules or makespan. The algorithm generates schedules of a particular subset of all possible schedules, called the active schedules.

The important considerations for choosing Giffler and Thompson (1960) as the basis of modification are (1) The algorithm is heuristic schedule that devise to find good solutions for really difficult problems robustly, (2) The algorithm limits the number of enumeration needed to find the active schedule, and (3) The algorithm is an appropriate algorithm for realistic job shop environment.

In this study, modified active schedule of Giffler and Thompson is used with dynamic slack time as second priority rules for breaking any tie. The dynamic slack time is built in Giffler and Thompson algorithm to accommodate the dynamic nature. The modified Giffler and Thompson algorithm is described below.

Procedures of the algorithm:

*Step 1.* Let $t = 1$ with $P_1$ being null. $S_1$ will be the set of operations with no predecessors

*Step 2.* Find $\{\phi_k\}$ for all $o_k$ in $S_t$

*Step 3.* Calculate $DST_k{}^* = min\{DST_k\}$ for all $o_k$ in $S_t$ .

*Step 4.* (a) Add $o_j$ in $P_t$ creating $P_{t+1}$, (b) Deleting $o_j$ from $S_t$ and creating $S_{t+1}$ by adding to $S_t$ the operation that directly follows the $o_j$ in its job, (c) Set $t$=$t$+1.

*Step 5.* If $t<nm$ go to step 2. Otherwise, stop.

Notations are: partial schedule of the $(t-1)$ scheduled operations as $P_t$, set of operations that can be scheduled at stage $t$, as $S_t$. The earliest time that operation $o_k$ in $S_t$ could be started, as $\sigma_k$, and $\phi_k$ will be the earliest time that operation $o_k$ in $S_t$ could be finished. $\phi_k = \sigma + p_k$, Furthermore, $p_k$ is processing time of $o_k$ and $R_j$ will bw the remaining process. $R_j = PC_j - PO o_{k-1}$. And then $PC_j$ as total prediction time to accomplish job $j$. Total operation time until operation $o_{k-1}$ as $PO o_{k-1}$. $D_j$ is due date of job $j$, and $T$ is current time. $DST_k$ as the dynamic slack time of operation $o_k$. $DST_k = D_j - T - R_j$. Finally, $n$ as number of final products, and $m$ will be the number of operations. The flow chart for the modified Giffler and Thompson is given in Figure 3.

## 2.3 Performance Measures to Evaluate the Scheduling Algorithms

In solving job shop scheduling problems, one of the objectives is to manage relation among the job due dates, workload and production capacity in order to reach the maximum factory's effectiveness and to meet the customer due date requirements. The efficiency of the factory can be measured in terms of various performance measures. To evaluate the performance of algorithms, the performance measures used in this study is mean tardiness. Tardiness occurs in shop floor if a job is completed after its due date. The reasons behind using the mean tardiness are explained as follows (1) The criteria based upon due dates, (2) The mean tardiness is appropriate when the early jobs take no reward and there are only the penalties acquired for late jobs.

$$\bar{T} = \frac{\sum_{i=1}^{n} Ti}{n}$$

where $\bar{T}$ is mean tardiness, and n is number of jobs to be scheduled.

## 3. TEST PROBLEMS

In this paper, mean tardiness is applied to evaluate the performance of RTP and modified Giffler and Thompson. The smaller the mean tardiness is, the better the algorithm. The test problems are generated with three main factors in job shop. The three main factors are the number of products, the number of machines in each workstation and tightness of due date. The problems will have three levels of number of products, three levels of number of workstations and three levels of tightness of due date. For instance, for the small level of number of product types, the number of generated product types has to within 2-7 types. The level of each main factor can be shown in Table 1. Table 2 presents the number of machines in each workstation that is applied in this set of test problems. The problem generation procedures are described below:

*Step 1:* Generate the level of the number of product types for each problem and the number of product types corresponding to the range in Table 1.
*Step 2:* Generate the order quantity for each product type.
*Step 3:* Generate processing time for each operation of each product type.
*Step 4:* Generate the level of the number of workstations for each problem.
*Step 5:* Generate the level of due date for each problem and due date for each product type.
*Step 6:* Generate process sequences for each product.
*Step 7:* Generate the release date for each product.

Twenty-seven test problems ($3^3$: 3 factors and 3 levels) with three replications were randomly generated with the procedure described earlier. Three replications are run in order to obtain an estimate of experimental error and more precise estimate the effect of factors.

**Table 1. Parameters of Test Problems**

| Parameter | Range | Unit | Remarks |
|---|---|---|---|
| Number of Product types | 2-7<br>8-14<br>15-20 | types<br>types<br>types | small level<br>medium level<br>large level |
| Number of workstations | 2-3<br>4<br>5-6 | workstations<br>workstations<br>workstations | small level<br>medium level<br>large level |
| Tightness of due date<br>(due date = release date + k* total operation time ) | k = 4 or 5<br>k=2 or 3<br>k = 1 | unit time | loose level<br>medium level<br>tight level |
| Operation time | 1-10 | Time units | |
| Number of machines | 1-2 | | Fixed |
| Quantity of order | 1-30 | units | |

**Table 2. Number of Machines for Test Problems**

| Workstation | Number of machine |
|---|---|
| 1 | 2 |
| 2 | 1 |
| 3 | 2 |
| 4 | 2 |
| 5 | 1 |
| 6 | 1 |

## 4. THE RESULTS OF THE TEST PROBLEMS

Algorithms are implemented with C# program and tested with the same data sets. Data sets for problem generation are generated in Excel. The model assumptions are as follows (1) One order at one time (2) General assumptions in scheduling algorithm are applied, and (3) Slack time (B) is zero for RTP algorithm.

To simulate the algorithms, first the data sets are developed with consideration of parameters of test problems. Then, the algorithms solve all test problems where each test problem has each data set and mean tardiness is computed.

For instance, three number of product type, three number of workstation and tight due date are applied with the time when order arrives. As mentioned in general assumptions for scheduling, the operation in a workstation should be completed before another operation is started. The data sets are shown in Table 3 below.

**Table 3. The Example of Data Sets**

| Order no. | Qty (units) | Workstation sequence | Processing time (in time units) | Order arrival (at time) | Due date (at time) |
|---|---|---|---|---|---|
| 1 | 1 | 2→ 1→3 | 7 ; 8 ; 3 | 0 | 18 |
| 2 | 5 | 2→ 1→3 | 2 ; 5 ; 8 | 10 | 85 |
| 3 | 10 | 3→ 1→2 | 4 ; 1 ; 3 | 13 | 93 |

RTP algorithm will schedule new order without changing the previous orders. In contrast, The Modified Giffler and Thompson algorithm will change dynamically when the new order arrives. It means the sequence of the jobs in each workstation can change depends on the earliest time of the feasible operation that could be finished and minimum dynamic slack time.

The results are analyzed by Minitab v13. Analysis of variance is applied with consideration of three-factors interactions. The factors in the test problems are random factors since the levels of factor are chosen randomly from a large possible levels and conclusion about the complete population of levels are required in these test problems (Montgomery, 1999).

The algorithms evaluated in this study are the RTP algorithm and modified Giffler and Thompson algorithm. Tests of various problem specifications were performed to conduct the performance of algorithms and investigate the algorithms.

### 4.1 RTP Algorithm Performance

The Analysis of variance for RTP is shown in Table 4. The sums of squares have been computed by the usual method. The result shows only interaction between number of product types and number of workstations is statistically significant. Figure 1 shows the effect of main factors. It shows the mean tardiness increases when the number of product types increases, the number of workstations increases and the due date tighter. From medium to large number of product types, the mean tardiness increases rapidly.

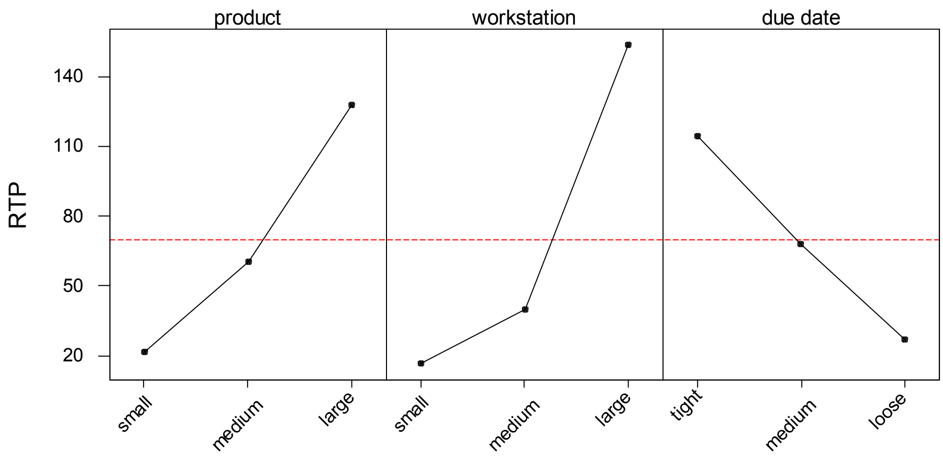


**Figure 1. The Effect Plot of Main Factors to Mean Tardiness of RTP Algorithm**

Moreover, the interaction between number of product types and number of workstations gives some interesting results. For small number of workstations, medium of number of product types gives the higher mean tardiness than large number of product types. In medium number of workstations, small number of product types also gives higher mean tardiness than medium number of product types. The interaction factors' plot is shown in Figure 2.

**Table 4. ANOVA of RTP Algorithm for Mean Tardiness**

| Factor | Type | Levels | Values |
|---|---|---|---|
| product | random | 3 | small medium large |
| workstation | random | 3 | small medium large |
| due date | random | 3 | tight medium loose |

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| product | 2 | 154652 | 77326 | 2.24 | 0.201 x |
| workstation | 2 | 289649 | 144825 | 3.97 | 0.087 x |
| due date | 2 | 103210 | 51605 | 3.00 | 0.140 x |
| product*workstation | 4 | 116123 | 29031 | 6.91 | 0.010 (*) |
| product*due date | 4 | 38754 | 9689 | 2.31 | 0.146 |
| workstation*due date | 4 | 46770 | 11692 | 2.78 | 0.102 |
| product*workstation*due date | 8 | 33626 | 4203 | 1.49 | 0.182 |
| Error | 54 | 152133 | 2817 | | |
| Total | 80 | 934917 | | | |
| Note : x Not an exact F-test. (*) significant factor | | | | | |

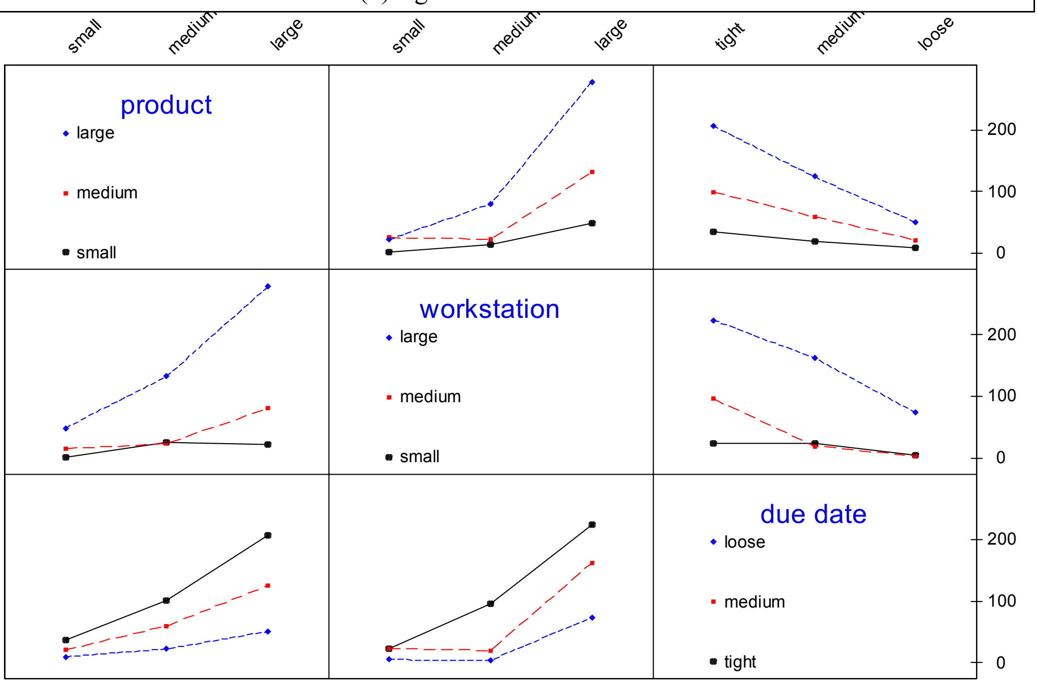


**Figure 2. The Plot of Interaction Factors to Mean Tardiness of RTP Algorithm**

### 4.2 Modified Giffler and Thompson Algorithm Performance

Table 5 shows the analysis of variance table for main factors and all interactions. The interaction factors between number of product type and tightness of due date and between number of workstation and tightness of due date are statistically significant. It seems that the modified Giffler and Thompson algorithm is very sensitive relate to tightness of due date. It is reasonable since the objective of Giffler and Thompson algorithm is to minimize total completion time with dynamic slack time used as second priority rules for breaking any tie.

**Table 5. ANOVA of Modified Giffler and Thompson Algorithm for Mean Tardiness**

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| product | 2 | 6137.0 | 3068.5 | 1.62 | 0.307 x |
| workstation | 2 | 2415.0 | 1207.5 | 0.91 | 0.474 x |
| due date | 2 | 19892.5 | 9946.3 | 3.30 | 0.100 x |
| product*workstation | 4 | 826.3 | 206.6 | 1.00 | 0.463 |
| product*due date | 4 | 7585.8 | 1896.5 | 9.15 | 0.004 (*) |
| workstation*due date | 4 | 5291.4 | 1322.8 | 6.38 | 0.013 (*) |
| product*workstation*due date | 8 | 1658.7 | 207.3 | 1.90 | 0.079 |
| Error | 54 | 5887.4 | 109.0 | | |
| Total | 80 | 49694.1 | | | |
| Note : x Not an exact F-test. (*) significant factor | | | | | |

Figure 3 presents the effect of main factors. It shows the mean tardiness decreases rapidly from tight due date to medium due date. The interaction factors plot can be shown in Figure 4. Some interesting cases appeared such as on medium due date, small workstation has highest mean tardiness. It occurs because the mean tardiness of medium and large number of product types in small workstation are high. Moreover, Loose due date gives zero tardiness even though number of workstations and number of product types are large.

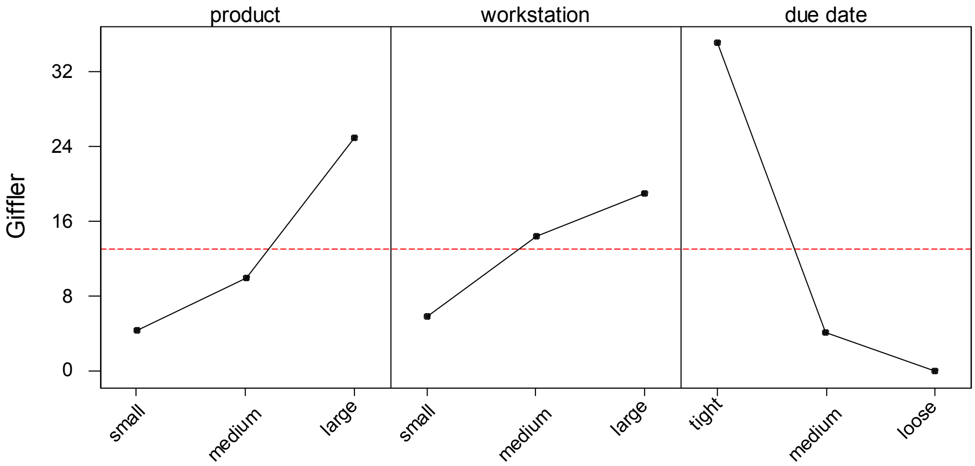


**Figure 3. The Effect Plot of Main Factors to Mean Tardiness of Modified Giffler and Thompson**

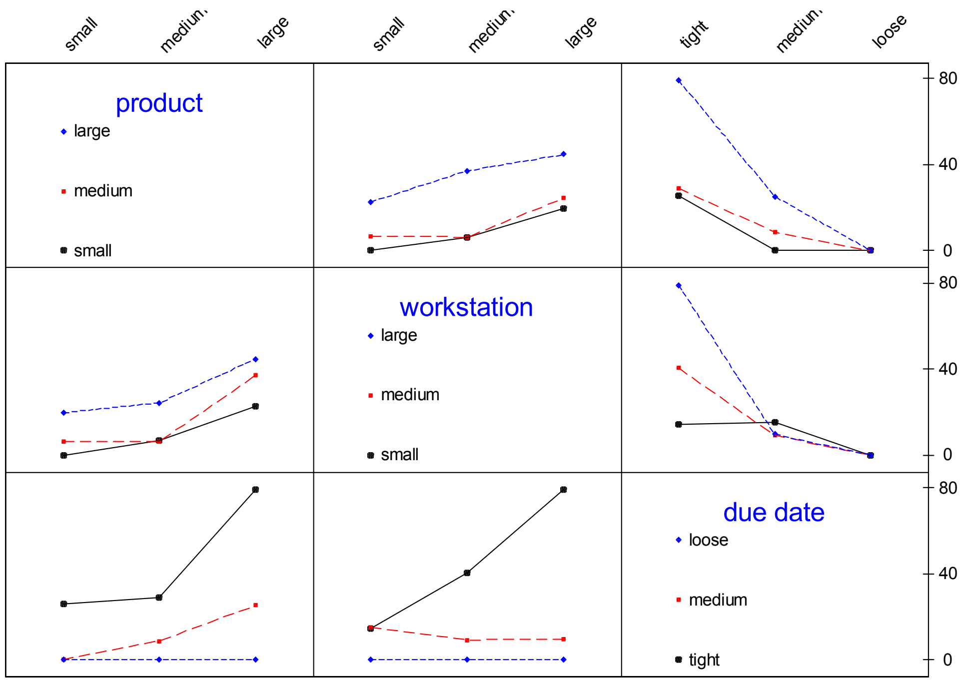


**Figure 4. The Plot of Interaction Factors to Mean Tardiness of Modified Giffler and Thompson**

### 4.3 Comparison of Mean Tardiness

Mean tardiness values obtained from RTP and modified Giffler and Thompson algorithms are analyzed in the following section. The *Paired t test* with 95% significance level is applied to compare and investigate the efficiency of the algorithms. The *Paired t test* is applied since the same data sets are used in the algorithms.

Algorithms are compared to observe the difference mean tardiness significantly by the *Paired t test hypothesis*. The hypothesis is constructed as follows:

$H_o$ : mean tardiness of RTP - mean tardiness of modified Giffler and Thompson≤0

$H_1$ : mean tardiness of RTP - mean tardiness of modified Giffler and Thompson>0

The result shows that difference between mean tardiness of RTP algorithm and modified Giffler and Thompson algorithm is significantly greater than zero. The mean tardiness and standard deviation of algorithms are shown in Table 6.

**Table 6. Result of *Paired t test* for Mean Tardiness**

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| RTP<br>Giffler | 81<br>81 | 70.0<br>13.1 | 108.1<br>24.9 | 12.0<br>2.8 |
| Difference | 81 | 57.0 | 94.7 | 10.5 |
| 95% lower bound for mean difference: 39.4<br>T-Test of mean difference = 0 (vs > 0): T-Value = 5.41 P-Value = 0.000 | | | | |

It seems that modified Giffler and Thompson is more capable than RTP in term of lower mean tardiness. It happens since RTP only considers the new order and assumes that the previous orders have the fixed schedule. On the contrary, modified Giffler and Thompson always updates the schedule when the new order arrives. The advantage of updated schedule is the job can be more flexible to be placed first when same operations between orders are needed.

## 5. CONCLUSION AND RECOMMENDATION

Based on the results obtained from the tests of problems, the following conclusions are drawn:

- The interaction between number of product types and tightness of due date affects mean tardiness of modified Giffler and Thompson algorithm
- The interaction of number of product types, number of workstations and tightness of due date also affects mean tardiness of RTP algorithm.
- Modified Giffler and Thompson is significantly better than RTP algorithm in terms of lower mean tardiness.

This study shows good performance of modified Giffler and Thompson algorithm even though it still requires further analysis for real-world application. However, the modified Giffler and Thompson algorithm is an alternative algorithm to schedule the jobs dynamically. The recommendations for further study are as follows:

- In this study, the dependent setup times are ignored. However, the modified scheduling algorithm can be developed to include dependent setup times. Further study on this subject is recommended.
- The decision support system for scheduling algorithm for a real-world application should be considered.

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