The Learning and Forgetting Effects of Dynamic Workers on the Performance of Dispatching Rules in Flow Shops

Horng-Chyi HORNG
and
Shu-Pei HU

Department of Industrial Engineering and Management, Chaoyang University of Technology
Wufong Township, Taichung County 41349, Taiwan
Presentation Outline

- Introduction
- Learning and Forgetting
- Simulation Construction
- Experimental Design
- Results and Analysis
- Conclusions
Introduction

- The problem of worker shortage comes along with the decreasing birth rate for the recent decade in Taiwan.
- One possible solution is training workers to become so-called *multitasking workers*.
- The flexibility of production scheduling increases when adopting multitasking workers, however, so does the complexity.
- The purpose of this study is to evaluate how the performance of *dispatching rules* affected by the *learning and forgetting effects* of workers.
Commonly used dispatching rules

- **Flow shops**

<table>
<thead>
<tr>
<th>Dispatching Rules</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT</td>
<td>$\min Z_{ij} = r_i$</td>
</tr>
<tr>
<td>AT-RPT</td>
<td>$\min Z_{ij} = r_i - rk_i$</td>
</tr>
<tr>
<td>FIFO</td>
<td>$\min Z_{ij} = r_{ij}$</td>
</tr>
<tr>
<td>PT/TIS</td>
<td>$\min Z_{ij} = P_{ij} / (t-r_i)$</td>
</tr>
<tr>
<td>SPT</td>
<td>$\min Z_{ij} = P_{ij}$</td>
</tr>
</tbody>
</table>

Worker assignment rules

- Two categories: “when” and “where”.
- Adopting **CEN** (centralized): the most flexible “when” rule that move away a worker whenever he/she completed the current job.
- Adopting **FCFS** (first come first serve): a “where” rule that prevents jobs waiting in a queue for too long.

Learning and Forgetting

- **Learning effects**
  - The efficiency of a worker in processing jobs at a certain station shall improve as the number of jobs he/she continuously completed increases.

- **Forgetting effects**
  - The deteriorating of a worker’s efficiency in processing jobs at a certain station as he/she, for some reasons was removed away from that station, stopped processing the same jobs for a period of time.

Models for learning and forgetting

- **Learning model – Mazur and Hastie (1978)**

  \[ y_x = k \left( \frac{x + p}{x + p + r} \right) + \varepsilon_x \]

- **Adding forgetting effects – Nembhard and Uzumeri (2000)**

  \[ y_x = k \left( \frac{xR_x^\alpha + p}{xR_x^\alpha + p + r} \right) + \varepsilon_x \]
Simulation Construction

- A hypothetical multi-station, single-server flow shop.

- Performance measurements:
  - mean flowtime of jobs
  - maximum flowtime of jobs, and
  - work-in-process (WIP).
Experimental Factors

- **number of stations:** 10, 20, and 30;
- **number of multitasking workers:** 10, 20, and 30;
- **processing time:** Normal(3,12), Uniform(1, 5), and Exponential(3) for coefficient of variation (CV) equals to 33.33%, 38.49%, and 100%, respectively; and
- **utilization rate:** 75%, 82.5%, and 90%.
## Experimental Design (I)

<table>
<thead>
<tr>
<th>Stages</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1\text{st} stage</td>
<td>No learning nor forgetting effects</td>
</tr>
<tr>
<td>2\text{nd} stage</td>
<td>Only learning effects</td>
</tr>
<tr>
<td>3\text{rd} stage</td>
<td>Learning effects with complete forgotten</td>
</tr>
<tr>
<td>4\text{th} stage</td>
<td>Learning effects with constant forgetting rate</td>
</tr>
<tr>
<td>5\text{th} stage</td>
<td>Learning effects with random forgetting rate</td>
</tr>
</tbody>
</table>
The 2nd stage learning model

Production Rate

$k$

0

Time

Worker assigned to other station
The 3rd stage learning and forgetting model

Production Rate

Time

Worker assigned to other station

k

0
The 4th stage learning and forgetting model

Production Rate

\[ k \]

0

Time

Worker assigned to other station
The 5\textsuperscript{th} stage learning and forgetting model

Production Rate vs Time

Worker assigned to other station

$k$

0
At each stage, a $2^2$ factorial design with $n_c = 3$ center points is adopted as guideline for performing simulation experiments.

Two major factors are number of station and utilization rate.

At each simulation run, there are 30 replications for statistical comparison purposes. Replication length is set to be 12,500 minutes in which the first 2,500 minutes is the system warm-up period.
Results and Analysis

- Simulation results from the 1st stage and 2nd stage serve as fundamental basis for comparison with subsequent stages one by one.

- The 1st stage simulation results are validated and compared to those mentioned in the literature.
  - Mean flowtime ~ SPT and PT/TIS
  - WIP ~ SPT and PT/TIS
  - Maximum flowtime ~ AT, FIFO, and AT-RPT
Best rule(s) from the 2\textsuperscript{nd} stage experiment for large system with high utilization rate

<table>
<thead>
<tr>
<th></th>
<th>NORM</th>
<th>UNIF</th>
<th>EXPO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\bar{F}$</td>
<td>$F_{\text{max}}$</td>
<td>$WIP$</td>
</tr>
<tr>
<td><strong>2\textsuperscript{nd} Stage</strong></td>
<td>SPT PT/TIS AT-RPT FIFO AT</td>
<td>SPT PT/TIS SPT PT/TIS</td>
<td>SPT PT/TIS AT-RPT FIFO AT</td>
</tr>
<tr>
<td><strong>1\textsuperscript{st} Stage</strong></td>
<td>SPT PT/TIS FIFO</td>
<td>SPT PT/TIS SPT PT/TIS</td>
<td>SPT PT/TIS AT-RPT FIFO AT</td>
</tr>
</tbody>
</table>
Best rule(s) from the 3rd stage experiment for small system with low utilization rate

<table>
<thead>
<tr>
<th></th>
<th>NORM</th>
<th></th>
<th></th>
<th>UNIF</th>
<th></th>
<th></th>
<th>EXPO</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$F$</td>
<td>$F_{max}$</td>
<td>WIP</td>
<td>$F$</td>
<td>$F_{max}$</td>
<td>WIP</td>
<td>$F$</td>
<td>$F_{max}$</td>
</tr>
<tr>
<td>3rd</td>
<td>SPT</td>
<td></td>
<td>SPT</td>
<td>SPT</td>
<td></td>
<td>SPT</td>
<td>AT FIFO</td>
<td></td>
</tr>
<tr>
<td>Stage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SPT</td>
<td></td>
</tr>
<tr>
<td>2nd</td>
<td>SPT</td>
<td>SPT</td>
<td>SPT</td>
<td>SPT</td>
<td>SPT</td>
<td>SPT</td>
<td>FIFO SPT</td>
<td>SPT</td>
</tr>
<tr>
<td>Stage</td>
<td>PT/TIS</td>
<td></td>
<td>PT/TIS</td>
<td>PT/TIS</td>
<td></td>
<td>PT/TIS</td>
<td>PT/TIS</td>
<td></td>
</tr>
<tr>
<td>1st</td>
<td>SPT</td>
<td>AT</td>
<td>SPT</td>
<td>SPT</td>
<td>AT</td>
<td>SPT</td>
<td>AT FIFO</td>
<td>SPT</td>
</tr>
<tr>
<td>Stage</td>
<td>PT/TIS</td>
<td>RPT</td>
<td></td>
<td>AT-RPT</td>
<td></td>
<td></td>
<td>SPT</td>
<td></td>
</tr>
</tbody>
</table>

Best rule(s) from the 3rd stage experiment for small system with low utilization rate.
Best rule(s) from the 4\textsuperscript{th} stage experiment for medium-size system with medium utilization rate

<table>
<thead>
<tr>
<th>Stage</th>
<th>NORM</th>
<th>UNIF</th>
<th>EXPO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\overline{F})</td>
<td>(F_{\text{max}})</td>
<td>WIP</td>
</tr>
<tr>
<td>4\textsuperscript{th} Stage</td>
<td>SPT</td>
<td>AT-RPT AT FIFO</td>
<td>SPT</td>
</tr>
<tr>
<td>2\textsuperscript{nd} Stage</td>
<td>SPT PT/TIS</td>
<td>AT-RPT AT</td>
<td>SPT PT/TIS</td>
</tr>
<tr>
<td>1\textsuperscript{st} Stage</td>
<td>SPT PT/TIS</td>
<td>AT-RPT AT</td>
<td>SPT PT/TIS</td>
</tr>
</tbody>
</table>
Best rule(s) from the 5th stage experiment for small system with high utilization rate

<table>
<thead>
<tr>
<th>Stage</th>
<th>NORM</th>
<th>UNIF</th>
<th>EXPO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Stage</td>
<td>SPT PT/TIS</td>
<td>AT-RPT</td>
<td>SPT PT/TIS</td>
</tr>
<tr>
<td>2nd Stage</td>
<td>SPT PT/TIS</td>
<td>AT-RPT</td>
<td>SPT PT/TIS</td>
</tr>
<tr>
<td>5th Stage</td>
<td>SPT PT/TIS</td>
<td>AT-RPT</td>
<td>SPT PT/TIS</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>$\bar{F}$</th>
<th>$F_{\text{max}}$</th>
<th>WIP</th>
<th>$\bar{F}$</th>
<th>$F_{\text{max}}$</th>
<th>WIP</th>
<th>$\bar{F}$</th>
<th>$F_{\text{max}}$</th>
<th>WIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Stage</td>
<td>SPT PT/TIS</td>
<td>AT-RPT</td>
<td>SPT PT/TIS</td>
<td>AT-RPT</td>
<td>SPT PT/TIS</td>
<td>AT-RPT</td>
<td>SPT PT/TIS</td>
<td>AT-RPT</td>
<td>SPT PT/TIS</td>
</tr>
<tr>
<td>2nd Stage</td>
<td>SPT PT/TIS</td>
<td>AT-RPT</td>
<td>SPT PT/TIS</td>
<td>AT-RPT</td>
<td>SPT PT/TIS</td>
<td>AT-RPT</td>
<td>SPT PT/TIS</td>
<td>AT-RPT</td>
<td>SPT PT/TIS</td>
</tr>
<tr>
<td>5th Stage</td>
<td>SPT PT/TIS</td>
<td>AT-RPT</td>
<td>SPT PT/TIS</td>
<td>AT-RPT</td>
<td>SPT PT/TIS</td>
<td>AT-RPT</td>
<td>SPT PT/TIS</td>
<td>AT-RPT</td>
<td>SPT PT/TIS</td>
</tr>
</tbody>
</table>
Conclusions

- In general, SPT is the best dispatching rule for the mean flowtime and WIP criteria. On the other hand, AT and AT-RPT perform better than others in the maximum flowtime criterion.

- Only when the system is relatively small with lower utilization rate, does the learning effect without forgetting effect produces different ranking of best rules than that of no learning effect case.

- The rule PT/TIS is a good candidate for the mean flowtime and WIP criteria. However, it is significantly influenced by the models for the forgetting effects of workers.

- The incorporation of the forgetting effects of workers to the system actually changes the rankings of best rules in statistical sense.
Research Directions

- Considering the effects caused by the shortage of workers;
- Incorporating more worker assignment rules; and
- Examining the effects of learning and forgetting effects on other production systems, such as job shops.
Thanks for listening!