A model technique for loading and scheduling problems in FMS

Mansour Abou Gamila, Saeid Motavalli (2003)
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Introduction

❖ background

• FMS goal:
  ✓ Flexibility of low volume production
  ✓ Efficiency of high volume mass production

➢ Limited by the availability of equipment
  → A proper pre-planning is necessary to achieve efficiency, flexibility, utilization.

• Decision
  ✓ Selection of machines
  ✓ Assignment of operations and required tools to machines to be processed

• Operational policy in FMS
  ✓ Tool movement policy
  ✓ Part movement policy (used in this paper)
Issues in FMS

❖ Decisions in FMS

• Loading in FMS:
  ✓ Allocation of operations and required tools to machines or workstations subject to resource and technological constraints of the system.
  ✓ One route policy → alternative route policy

• Routing decisions in FMS
  ✓ Determining the route or sequence of operations for each part
  ✓ Tool loading defines and restricts machines’ capability → loading and routing consider together

• Scheduling problems in FMS
  ✓ Production scheduling concerns the efficient allocation of resources over time for the manufacture of goods.

• System utilization
  ✓ The system utilization is computed as the ratio of the actual system production over the total capacity of the system. \( \text{Utilization} = \frac{UK}{\text{total busy time}} / \text{max completion time} \)

• Tool management in FMS
  ✓ Tool management issues affect the productivity of FMS. Tool management is essential to ensure flexibility in tooling, and is responsible for ensuring that the right tools are on the right machines at the right time.
Proposed model

❖ Problem description

• Problem
  – Loading and scheduling problems in FMS system contains several numerical machines

• Objective (Difference from existing research)
  – Minimizing the sum of maximum completion time, material handling time and total processing time

• Decision variables
  – Tool allocation, operation allocation, operation sequencing

• Assumption
  – The machines are not identical
  – The distance between machines are equal
  – No breakdowns for machines or material handing systems
  – There is limited number of each tool type
  – All tools are new at the initial stage
  – Each tool and each operation are assigned only to one machine
  – The setup costs differ according to the size and shape of the parts

• Constraints
  – Tool magazine capacity
  – Tool life
  – Setup cost
Proposed model

Notations

- $I$ Machine $I = 1, 2, \ldots, m$
- $J$ Part $j = 1, 2, \ldots, n$
- $R(J)$ Operation $R(J) = 1, 2, \ldots, q(j)$
- $L$ Tool $L = 1, 2, \ldots, w$
- $A$ Machine stage $A = 1, 2, \ldots, z$
- $S$ Maximum completion time
- $T_L$ Tool life for type $L$ tool
- $P_{R(J), J, L, I}$ Processing time for operation $R(J)$ of part $J$ using tool $L$ on machine $I$
- $C_{R(J), J, L, I}$ Cost of operation $R(J)$ of part $J$ using tool $L$ on machine $I$
- $C$ Total target cost for the processing
- $X_J$ Number of movements of part $J$ between machines
- $C_J$ Setup cost for part $J$
- $D_J$ Due date of part $J$
- $C_{ SETUP }$ Limit of setup cost
- $S_I$ Tool magazine capacity of machine $I$

Decision variables

- $X_{L,I} = 1$ if tool $L$ is assigned to machine $I$; 0 otherwise
- $Y_{R(J), J, L, I, A} = 1$ if operation $R(J)$ of part $J$ is assigned to machine $I$ containing tool $L$ in stage $A$; 0 otherwise
Proposed model

\*Integrated planning model*

- **Objective function:**

  \[
  \text{Min } T = S + \sum_{J=1}^{n} X_J + \sum_{A=1}^{z} \sum_{I=1}^{m} \sum_{L=1}^{w} \sum_{J=1}^{n} \sum_{R(J)=1}^{q(J)} P_{R(J),J,L,I} * Y_{R(J),J,L,I,A}
  \]

  \[
  \text{Maximum completion time}
  \]

  \[
  \text{Material handling time}
  \]

  \[
  \text{Total processing time}
  \]

- **Constraints:**

  1. \[\sum_{A=1}^{z} \sum_{I=1}^{m} \sum_{L=1}^{w} Y_{R(J),J,L,I,A} = 1\]
     \[\forall R(J), J\]
     \[\text{Operation and tool assignment}\]

  2. \[\sum_{A=1}^{z} \sum_{I=1}^{m} \sum_{J=1}^{n} \sum_{R(J)=1}^{q(J)} P_{R(J),J,L,I} * Y_{R(J),J,L,I,A} \leq T_{L,L}\]
     \[\forall L\]
     \[\text{Tool life constraints}\]

  3. \[\sum_{A=1}^{z} \sum_{I=1}^{m} \sum_{J=1}^{n} \sum_{R(J)=1}^{q(J)} P_{R(J),J,L,I} * Y_{R(J),J,L,I,A} \leq S\]
     \[\forall I\]
     \[\text{Maximum processing constraints}\]

  4. \[\sum_{A=1}^{z} \sum_{I=1}^{m} \sum_{J=1}^{n} \sum_{R(J)=1}^{q(J)} P_{R(J),J,L,I} * Y_{R(J),J,L,I,A} \leq D_J\]
     \[\forall J\]
     \[\text{Due date constraints}\]

  5. \[\sum_{A=1}^{z} \sum_{I=1}^{m} \sum_{J=1}^{n} \sum_{R(J)=1}^{q(J)} A(Y_{R(J)+1,J,L,I,A} - Y_{R(J),J,L,I,A}) \geq 0\]
     \[\forall R(J), J, L, I\]
     \[\text{Precedence relationship}\]

  6. \[\sum_{I=1}^{m} \sum_{L=1}^{w} \sum_{R(J)=1}^{q(J)} Y_{R(J),J,L,I,A} \leq 1\]
     \[\forall A, J\]
     \[\text{Operation assignment constraints}\]

  7. \[\sum_{I=1}^{m} X_{L,I} \leq 1\]
     \[\forall L\]
     \[\text{Tool assignment constraints}\]

  8. \[\sum_{L=1}^{w} X_{L,I} \leq S_I\]
     \[\forall I\]
     \[\text{Tool magazine capacity}\]

  9. \[\sum_{A=1}^{z} \sum_{I=1}^{m} \sum_{L=1}^{w} \sum_{J=1}^{n} \sum_{R(J)=1}^{q(J)} C_{R(J),J,L,I} * Y_{R(J),J,L,I,A} \leq C\]
     \[\forall R(J), J, L, I\]
     \[\text{Target cost limit}\]

  10. \[X_J = \sum_{I=1}^{m} | Y_{R(J)+1,J,L,I,A} - Y_{R(J),J,L,I,A} | / 2\]
      \[\forall R(J), J, L, A\]
      \[\text{Part movements}\]

  11. \[\sum_{J=1}^{n} X_J * C_J \leq C_{SETUP}\]
      \[\forall R(J), J, L, A\]
      \[\text{Setup cost limit}\]
Proposed model

- **Heuristic method for detailed parts scheduling**
  - Scheduling the operations on machines to minimize the completion time.
    - Step 0: Obtain the results of assignment of operations and tool from the IP model.
    - Step 1: Start with the first operation on each part, and with first stage for each machine. $R(J) = 1, A = 1$.
    - Step 2: $EF_{R(J)} = ES_{R(J),M,A} + P_{R(J),M}$ (the completion time of operation $R(J)$). Increase $R(J)$ and $A$ by one. $R(J) = R(J) + 1, A = A + 1$.
    - Step 3: Check the machine availability for the operation $R(J)$; the start time of operation $R(J)$ as: $ES_{R(J),M,A} = \max (EF_{R(J)-1}, EF_{M,K-1})$
    - Step 4: Check if all operations are scheduled; calculate the completion time and stop, otherwise, go to step 2.
Illustrative examples and analysis of results

Example 1

Parameter
Machine 4 Part 4 Operation 4 Tool magazine capacity 40 Tool type 20 tool life 150min
Date is take from Sarin and Chen(1987) (Paper Table 1,2)

Result
Illustrative examples and analysis of results

Example 1

Comparison

<table>
<thead>
<tr>
<th></th>
<th>Set up cost</th>
<th>Processing cost</th>
<th>Total time</th>
<th>Max. completion time</th>
<th>Completion cost</th>
<th>Total cost</th>
<th>Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sarin and Chen</td>
<td>1050</td>
<td>3590</td>
<td>1369</td>
<td>558</td>
<td>5833</td>
<td>6903</td>
<td>61</td>
</tr>
<tr>
<td>Our model</td>
<td>790</td>
<td>4540</td>
<td>1201</td>
<td>403</td>
<td>6094</td>
<td>6884</td>
<td>74.5</td>
</tr>
</tbody>
</table>

Analysis

1. Decreasing the total processing time from 1369 to 1201 min, a decrease of 12.3%.
2. Decreasing the maximum completion time from 558 to 403 min, a decrease of 27.8%.
3. Decreasing the set up cost from 1050 to 790, a decrease of 24.8%.
4. Increasing the utilization from 61% to 74.5%.
5. Although the processing cost for the model is higher, the total cost decreased from 6903 to 6884 as a result decreasing the maximum completion time, which increase the production rate and reduces the idle time.
Illustrative examples and analysis of results

Example 2

Parameter

Machine 5 Part 5 Operation 5 Tool magazine capacity 60 Tool type 22 tool life 150min
Date can be seen on Paper Table 5,6

Result

<table>
<thead>
<tr>
<th>Assignment of tools and operations and machine utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machines</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>M1</td>
</tr>
<tr>
<td>M2</td>
</tr>
<tr>
<td>M3</td>
</tr>
<tr>
<td>M4</td>
</tr>
<tr>
<td>M5</td>
</tr>
<tr>
<td>Sum</td>
</tr>
</tbody>
</table>

Analysis

1. Total processing time is 1796.
2. The target cost is 5200, and the actual total cost is 2080.
3. The total setup cost is 1300, the actual setup cost is 1210.
4. The total system utilization is 81.1%. 
Conclusion

❖ Overview

• Problem
  – Loading and scheduling problems in FMS with several numerical machines
    ✓ Setup cost considering
    ✓ A objective considering minimizing maximum completion time, material handling time and total processing time

• suggest
  – A integrated planning model
  – Heuristic method for detailed parts scheduling

❖ Adv. & Disadv.
THANK YOU