A Scheduling Model for Production System Considering Material Handling Operations

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ABSTRACT

In most techniques, production scheduling only consider production machines as resources. These techniques generally do not consider the material handling operations by assuming that the material handling equipments are always available and the handling time can be ignored. In systems with significant material handling time, ignoring the material handling operations may cause the material handling equipment allocation that does not fit the need for part transportation. In this study, a scheduling model considering material handling equipments as resource will be developed. The developed model will start from priority dispatching technique, by adding necessary steps to consider the material handling equipments.

Keywords: *Scheduling, Material Handling, Priority Dispatching Technique*

1. Background

Scheduling is the allocation of resources to perform a set of tasks based on time. To determine this allocation, various techniques have been developed using optimization and heuristic approaches. In the techniques currently available, scheduling only consider production machinery as a resource [1]. These techniques do not consider the material handling process by assuming that the process can be done using material handling equipments available and the processing time can be ignored.

In certain production systems, such as production system in Balai Yasa Jembatan Kereta Api (railway bridge workshop), Bandung, the time required to perform the material handling process has a significant proportion to the total processing time. Thus, the material handling time in this type production systems can not be ignored. The common reason of this condition is the size or mass of material, so that most or all of the material handling process must use special equipment, and the material handling time can not be ignored.

In the production systems with significant proportion of material handling time, the material handling equipment should be regarded as a source as production machinery, and should be considered in scheduling. Without considering the scheduling of material handling equipment, it is possible that at a time, work-in-process parts are waiting to be transported from one station to another station because of all material handling equipments are being used to transport components, while at the other time, all material handling equipments are idle. Therefore, in this type production system, scheduling needs to consider the material handling time and equipments.

This research aims to:

1. Create a flow shop production scheduling model for systems with significant proportion of material handling time.
2. Apply the model to solve the problems occurred in Balai Yasa Jembatan Kereta Api, Bandung.

2. Literature Review

There are some recent developments in scheduling considering material handling operations. Lei and Wang [2] considered the problem of cyclic scheduling of two hoists. Bilge and Ulusoy [3] exploited the interactions between the machine scheduling and the scheduling of the material handling system in an FMS by addressing them simultaneously. Das and Spasovic [4] presented a straddle scheduling procedure that can be used by a terminal scheduler to control the movement of straddle carriers. Khayat et al. [5] proposed an integrated formulation of the combined production and material handling scheduling problems. Babiceanu et al. [6] presented a solution for scheduling material handling devices in the cellular manufacturing environment using the holonic control approach. Finally, Anwar and Nagi [7] considered the simultaneous scheduling of material handling transporters (such as automatic guided vehicles or AGVs) and manufacturing equipment (such as machines and work centers) in the production of complex assembled product.

This paper will develop a scheduling model considering material handling operations. It will be developed from Baker's job shop scheduling [1]. The material handling consideration will refer to the system designed by Apple [8].

3. Model Development

3.1 Problem Modelling

Problem of scheduling production machines and material handling equipments will be developed gradually. The problem is developed from simple to complex in several stages:
1. Scheduling one production machine and one material handling equipment.
2. Scheduling *m* production machines and one material handling equipment.
3. Scheduling *m* production machines and *h* independent material handling equipments.
4. Scheduling *m* production machines and *h* dependent material handling equipments.

A. Scheduling one production machine and one material handling equipment

Examples of scheduling one production machine and one material handling equipment can be seen in Figure 1. All products are processed by one machine and supported by one material handling equipment, but each has different number of repetitions and operation time. Problems like this have a general form as shown in Figure 2. The routing of this problem is shown in Table 1.

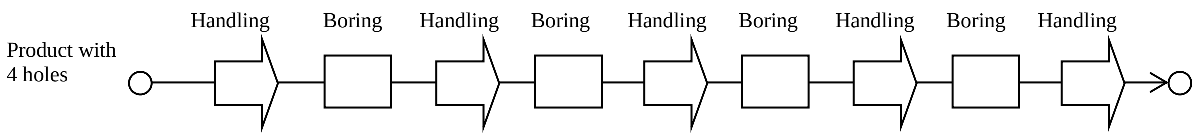

Figure 1: An example of scheduling one material handling equipment and one machine

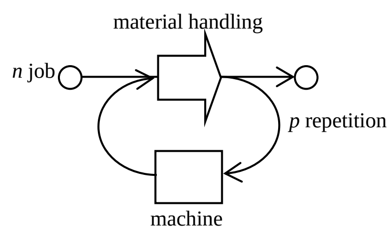

Figure 2: An example of scheduling one machine and one material handling

Table 1. Routing of problem in Figure 2

Job (*i*)	Operation (*j*)					
	1	2	3	…	2*p*	2*p*+1
1	H	M	H	…	M	H
⋮	H	M	H	⋮	M	H
n	H	M	H	…	M	H

M: machine; H: material handling

B. Scheduling *m* production machines and one material handling equipment

Examples of scheduling *m* production machines and one material handling equipment can be viewed in Figure 3. All jobs are processed by some machines and transported by one material handling equipment, with different sequence and operation time. The problem has a common model as shown in Figure 4. The routing of this problem is shown in Table 2.

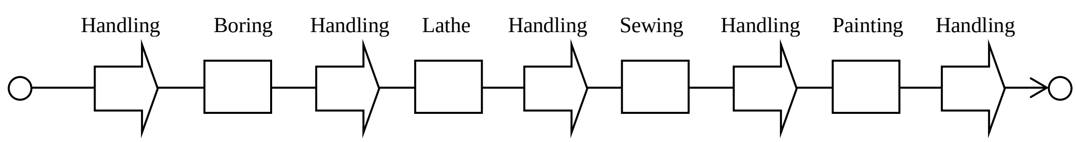

Figure 3: Examples of scheduling *m* machines and one material handling

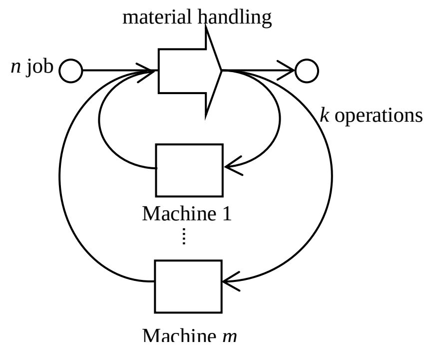

Figure 4: General form of scheduling *m* machines and one material handling equipment

Table 2. Routing of problem in Figure 4

Job (i)	Operation (j)					
	1	2	3	…	$2k$	$2k+1$
1	H	M_{ij}	H	…	M_{ij}	H
⋮	H	M_{ij}	H	⋮	M_{ij}	H
n	H	M_{ij}	H	…	M_{ij}	H

M_{ij}: machine used in job i operation j; H: material handling

C. Scheduling *m* production machines and *h* independent material handling equipments

Examples of scheduling *m* production machines and *h* independent material handling equipments can be viewed in Figure 5. All jobs are processed by some machines and transported by some material handling equipments, with different sequence and operation time. The "independent" term means that the material handling equipments transport the jobs without any dependence or collaborative action with other. The problem has a common model as shown in Figure 6. The routing of this problem is shown in Table 3.

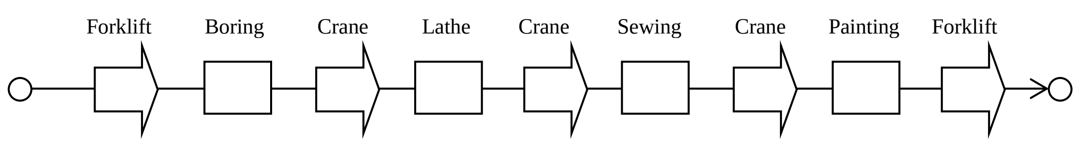

Figure 5: Examples of scheduling *m* machines and *h* independent material handling

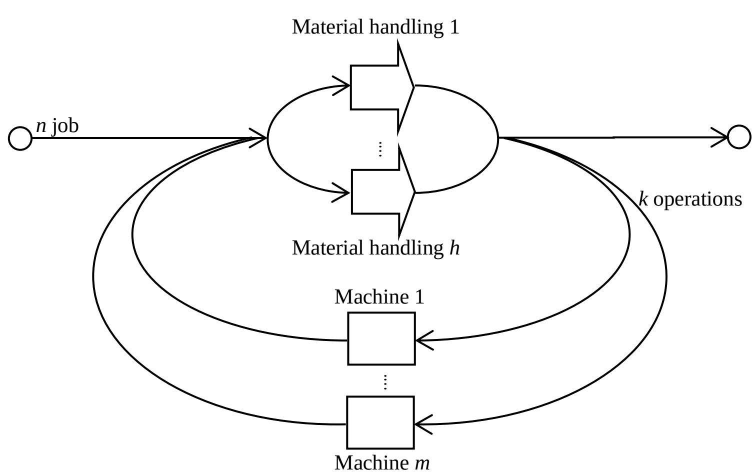

Figure 6: General form of scheduling *m* machines and one material handling equipment

Table 3. Routing of problem in Figure 6

Job (i)	Operation (j)					
	1	2	3	…	$2k$	$2k+1$
1	H_{ij}	M_{ij}	H_{ij}	…	M_{ij}	H_{ij}
⋮	H_{ij}	M_{ij}	H_{ij}	⋮	M_{ij}	H_{ij}
n	H_{ij}	M_{ij}	H_{ij}	…	M_{ij}	H_{ij}

M_{ij}: machine used in job i operation j; H: material handling used in job i operation j

D. Scheduling *m* production machines and *h* dependent material handling equipments

In the previous section, material handling equipments are assumed to work independently, do not affect each other. In the real system, it is possible that several material handling equipments have a mutual dependency (dependent).

Interdependence between some material handling equipments can occur in some conditions:

1. Selection of material handling equipment.
   Generally, machining and material handling operation have designated machines or material handling equipment required. However, in certain material handling operations, materials handling equipment which will be used is not determined before (some equipments are possible). If a material handling operation can be handled by more than one material handling equipment, the equipment used to handle this operation is the one that can perform operations earlier. The earliest completion of the operation depends on:
   - Ready time of each material handling equipment to be used.
   - Arrival time of each materials handling equipment in the displacement starting location.
2. Simultaneous use of resources.
   Generally, each operation, either machining or material handling operation, uses only one resource. However, it is possible that certain operations require more than one resource simultaneously. The examples are:
   - Use of some material handling equipments simultaneously. To lift a locomotive body weighing over 70 tons from its wheels, two overhead cranes of 36 tons haul powered are used simultaneously.
   - Use of materials handling equipment and production machines simultaneously. To drill a bar of bridge component, a drill machine is used assisted by an overhead crane to hold the bar.
3. Shared path.
   Movement of material handling equipments may use a path simultaneously (or alternately). In double girder overhead crane, one crane path (axis movement) is used by the two cranes. Therefore, when a crane will move from one location to another, another crane should not be in a location that will be passed through. In transport vehicles such as forklifts and tractors, track dependencies can also occur on paths that are used together by several equipments. If an equipment will be used, but the required path is being used by other equipment, then it should wait until the path they need is available.

The general form and the routing of scheduling *m* production machines and *h* dependent material handling equipments are the same with the independent one, as can be seen in Figure 6 and Table 3.

3.2 Scheduling Algorithm

An algorithm is developed to solve the scheduling problem described in Section 3.1. The algorithm refers to the problem of scheduling *m* machine scheduling production and *h* dependent material handling equipments, due to this problem is the most complex problem of the four problem types. This means that the algorithm is applicable for the three other simpler problems.

The scheduling process is based on notations and steps in the Priority Dispatching Technique [1]. The notations used in the model develompent are:

PS_t = partial schedule consists of t scheduled operations;
S_t = operations ready to be scheduled at stage t;
r_j = earliest time at which operation $j \in S_t$ can be started;
c_j = earliest time at which operation $j \in S_t$ can be completed;
D_{ij} = arrival time of job i in the j-th material handling operation;
t'_{ij} = total time of job i in the j-th material handling operation (including the arrival time).

The algorithm is described as follows.

Step 1. Suppose $t = 0$, $PS_i = 0$ and S_0 = set of operations without predecessors.
Step 2. If there are material handling operations in S_t:

a. If there are more than one material handling equipment that can be used, select a material handling equipment that capable to complete the operation earlier.
b. Determine r_j, the time when all material handling equipments can be used, regarding the use of paths by the equipments.

Step 3. For material handling operations at S_t, determine the arrival time D_{ij} based on the last location of the required material handling equipment. If some resources are used, the arrival time is the latest arrival time of all resources. Then, specify t'_{ij} by summing D_{ij} with material handling time specified in the routing.

Step 4. Considering r_j**,** determine $c^* = \min_{j \in St} \{c_j\}$ and the resource r^* where c^* would be done.

Step 5. For each operation $j \in S_t$ requires the resource r^* and has $r_j < c^*$, select a priority using the following stages:

a. Prioritize operations using less resource.
b. Select an operation using certain priority rule.

Add selected operation to PS_t so the partial schedule PS_{t+1} is obtained.

Step 6. For the partial schedule PS_{t+1} obtained from Step 5, update the following data.

a. Remove the scheduled operation j from S_t.
b. Create S_{t+1} by adding the operation succeeding the scheduled operation j.
c. Add t by one.

Step 7. Return to Step 2 to review PS_{t+1} and continue all the steps until all jobs are scheduled ($S_t = \{\}$).

4. Model Application

A problem is shown in the following. Table 4 and 5 shows the original routing and processing time of four jobs without the material handling operations.

Table 4. Original routing

Job	Operation		
	1	2	3
1	1	2	3
2	2	1	3
3	3	2	1
4	2	1	3

Table 5. Original processing time

Job	Operation		
	1	2	3
1	4	3	2
2	1	4	4
3	3	2	3
4	3	3	1

Materials handling operations in this system is performed based on the following description.

- The material handling equipments consist of 2 forklifts (number 4_1 and 4_2) and 2 overhead cranes (number 5_1 and 5_2).
- Transportation between two machines will use crane, and transportation between storage and machines will use forklift.
- Operations on Machine 3 need assistance of one crane, and material handling operations of Job 4 requires two material handling equipments (forklift or crane) simultaneously.
- Aisles in the plant are wide enough to pass by 2 forklifts as well. Meanwhile, two cranes are located on one line so that the position of each crane in the scheduling must be considered.

After including material handling operations, the job routing is updated as shown in Table 6. Further, Table 7 shows the transportation time between machines and storages in the plant.

Table 6. New routing

Job	Operation						
	1	2	3	4	5	6	7
1	4	1	5	2	5	3+5	4
2	4	2	5	1	5	3+5	4
3	4	3+5	5	2	5	1	4
4	4_{12}	2	5_{12}	1	5_{12}	3+5_{12}	4_{12}

Notes:
Shaded cells are material handling operations
4 or 5: one material handling is required
4_{12} or 5_{12}: two forklifts or two cranes are required
3+5: machine 3 is required assisted by a crane
3+5_{12}: machine 3 is required assisted by two cranes

Table 7. Transportation time

From	To				
	R. mat. storage	Machine 1	Machine 2	Machine 3	End pr. storage
Raw material storage	-	3	3	4	2
Machine 1	3	-	1	3	4
Machine 2	3	1	-	2	3
Machine 3	4	3	2	-	2
End product storage	2	4	3	2	-
Forklift park	2	3	4	5	2
Crane 1 park	-	1	1	2	-
Crane 2 park	-	2	1	1	-

Considering Table 6 and Table 7, and the machining time in Table 5, an updated processing time for both machining and material handling operations is then summarized in Table 8.

Table 8. Updated processing time

Job	Operation						
	1	2	3	4	5	6	7

1	9	4	5	3	9	2	5
2	7	1	6	4	13	4	6
3	8	3	6	2	9	3	8
4	7	3	5	3	13	1	7

Note: Shaded cells are material handling operations

Applying the algorithm developed in Section 3, a schedule of machinery and material handling equipments is shown in Figure 7.

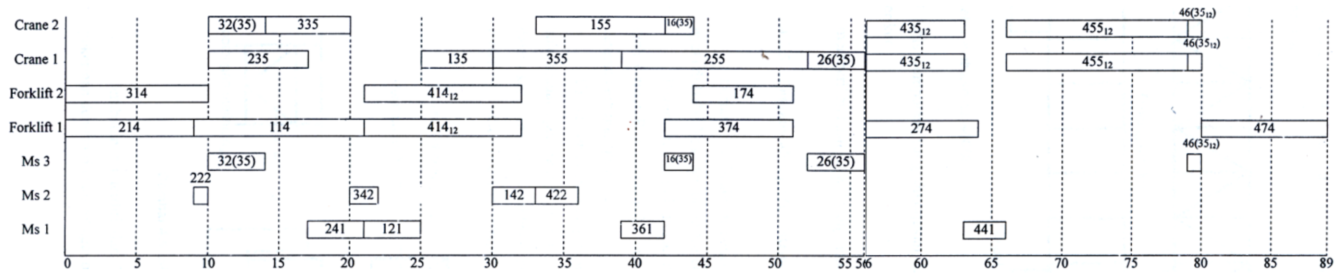

Figure 7: Final schedule for the given problem

The Gantt-chart in Figure 7 is important to analyze to understand how the model works. For example, see Job 2 with the operation sequence 214, 222, 235, 241, 255, 26(35) and 274. Remember that the odd sequence operations are material handling ones. So, the operation sequence of Job 2 switches alternately between machining operations (lower region) and material handling operations (upper region).

Further more, two-resource operation can be seen in the notation 26(35) in the Gantt-chart. The operation 26(35) appears in Machine 3 and crane 2, due to the operation requires both resources. The same appearance occurs in operation 32(35) and 16(35). Other two-resource operations with different notation are 414_{12}, 435_{12} and 455_{12}. Finally, a three-resource operation occurs in $46(35_{12})$ as can be seen in the Gantt-chart.

5. Concluding Remarks

The model developed in this paper works properly. The model is applicable for production systems with significant proportion of material handling operations. The model works by combining both machining operations and material handling operations in one routing table and one processing time table. The model can adopt special conditions of material handling operations, such as multi-resource operation, consideration of material handling equipment locations, the usage of machinery and material handling equipment simultaneously, and consideration of the route of material handling equipment movements. The model can also be extended to production systems using material handling equipment such as Automatic Guided Vehicle (AGV) and Robotic Guided Vehicle (RGV).

6. References

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