inimizing Production Flow Time in a Process and Assembly Job Shop

by Tjutju Tarliah Dimyati -

International Seminar on Industrial Engineering and Management (ISIEM) 2007

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Foreword

The first International Seminar on Industrial Engineering and Management (ISIEM) 2007 took place on August 29th– 30th at Menara Peninsula Hotel, Jakarta. The conference was jointly hosted through the collaboration between Industrial Engineering Department Trisakti University, Gunadarma University and Indonusa Esa Unggul University.

This proceedings collects papers covering a wide range of activities and provides an overview of critical research issues reflecting on past achievements and future challenges in the field of industrial engineering. The topics presented have been divided into the following categories: operations research, quality engineering and management, decision support systems and artificial intelligent, production systems, industrial management and ergonomics.

We want to thank all those individuals or groups who submitted papers for review and those whose papers were chosen for presentation at the conference and those who submitted manuscripts to be published in these proceedings. We also want to give a special thanks to the reviewers for their commitment, effort and dedication in undertaking the task of reviewing all of the abstracts that were submitted. Reviewing a large number of submission in a relatively short time frame is always challenging. Without their help and dedication, it would not be possible to produce the proceedings in such a short time frame. We highly appreciate all members of committee director, steering committee and organizing committee for mutual efforts and invaluable contributions for the success of the conference.

It is always a pleasure to host our colleagues from regional industrial engineering community to build networks and links that are essential parts for the development of industrial engineering in the future. In particular, this conference brought together researchers, academicians, practitioners and industries in the field of industrial engineering through presentation, discussion and dissemination of the research results, new acquired knowledge and technology to foster further cooperation and exchange of ideas to narrow the gap between their theoretical design and practical deployment.

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MINIMIZING PRODUCTION FLOW TIME IN A PROCESS AND ASSEMBLY JOB SHOP

Tjutju T. Dimyati
Department of Industrial Engineering - Pasundan University
adimyati@bdg.centrin.net.id

ABSTRACT

The research to date on assembly shop scheduling is considerably less extensive than the body of traditional job shop research, even though most jobs realistically involve assembly of some sort. Unlike simple job shops, no predominant sequencing rule has been determined for assembly shop scheduling. In this research, the problem of production scheduling in a single factory is addressed. To solve this problem, a mathematical model is formulated based on a given scheduling strategy. The objective of the model is the minimization of total production flow time (makespan). A heuristic algorithm is then developed to solve the model more efficiently. The solution obtained from the model provides a production plan for getting products through the system in a timely manner.

Keyword: Assembly shop scheduling

INTRODUCTION

Research in the deterministic production assembly job shop has been less extensive than that of the more simplified job shop. The primary reason is that in the assembly job shop there are precedence relations between jobs as well as operations, while in the general job shop there is only precedence between operations. Because of the computational complexity and the fact that the generation of optimal schedules is likely to require excessive computational time, independent of the methodology, the pursuit of "pure" optimal scheduling method is impractical. This means that the primary challenge faced by researchers is to developed an efficient solution methodology that generates near-optimal solutions with measurable performances.

Chen and Wilhelm (1993) presented a heuristic for the kitting problem in a multi-echelon assembly system. The objective was to allocate on-hand stock and anticipate future deliveries to kits to minimize total cost, consisting of job earliness, job tardiness, and in-process holding costs. The heuristic was shown to run in polynomial time in the worst case and appeared to be well suited for large scale industrial problems. A different work in the solution approach (based on integer programming model) was also presented (Chen and Wilhelm, 1994).

Doctor et al (1993) presented a model for scheduling in a job shop with assembly considerations. The objective pursued in the development of the model was maximizing the machine utilization subject to satisfying job due date requirement. A heuristic algorithm based on slack time and extra time was developed to solve the problem. The main conclusion by the authors was that the need to coordinate the completion time of components becomes much more critical in a high loads job shop. The disadvantage of this model is that the results obtained is only good for tree structure (BOM) with less than or equal to three levels.

Dimyati et al (2004) presented a Mixed Integer Linear Programming (MILP) model for scheduling in an assembly job shop to minimize total production flow time. The model was developed under the strategy where identical sub-jobs are consolidated or aggregated into super batches for processing. The main conclusion of the study was that the MILP model developed is computationally intensive as the number of jobs and integer variables increased.

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PROBLEM STATEMENT

Given an assembly shop and a set of N final assemblies (each final assembly consists of H_{ij} sub-assembly parts) with corresponding processing times, the problem is to find the optimal production plan in scheduling the different components for machining and assembly so as to minimize total production flow time (makespan). H_{ij} is defined as the number of components or sub-assemblies (sub-jobs) required for meeting the total demand of its direct parent.

MODEL DEVELOPMENT

As stated earlier, the objective of this study is to develop a model and a methodology for minimizing production time of jobs involving both machining and assembly operations in a production shop. In minimizing the total production flow time, technological ordering will specify the order in which each job is processed on various machines, while the solution methodology will determine the sequence of the jobs on the machines for processing.

Fundamental to this study are the assumptions on the production strategy where sub-jobs that are identical are considered as separate nodes as they occur in a bill of material (BOM). A sub-job is defined directly as a sub-assembly part or a component part. The number of sub-jobs (including the final job) is equal to the number of nodes in a BOM or product structure tree. These assumptions are the bases for the development of the mixed integer linear programming (MILP) model. Constraints for the given system are generated based on the given data and the underlying assumptions.

Required Data for Model Development

The data necessary for development of the model include the following:

- A master production schedule (MPS) covering the production period of interest exists.
- Information on the manufacturing batch size for each job and the operation sheet for each component part or sub-assembly that goes into the job. The operation sheet for each component part or sub-assembly type defines the routing and processing time per unit item on each machine in the route.
- A product structure tree or BOM for each finished product exists.

Model Characteristics

In shops that produce multiple assembled products, it is very common to find a given component or sub-assembly (sub-job) used in several end products. It is also common to find a given component or sub-job used at more than one level in a particular end product structure. In this study, when multiple end products are scheduled together for production and the end products use the same component or sub-job, the model treats each component or sub-job for each product as a separate item for scheduling. This is also true when the same component or sub-job is used at more than one level or node in the same end product. In other words, identical components or sub-jobs belonging to one or more jobs are considered as separate nodes as they occur. The objective of the model is to produce a set of sequence over all machines which will minimize total production flow time.

Assumptions

The following assumptions are made in developing the model:

- All parts necessary for manufacturing a final product are produced at the same facility. Parts or sub-assemblies purchased from outside sources are considered as components or raw materials at the target facility. For every final product, the entire demand per period is produced as a single batch

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- Since it is dealing with a single factory that produces all required parts that go into making its final product, all materials necessary for production are simultaneously available at time zero or as needed
- All final products are shipped to the customers immediately
- Transportation time between machines is instantaneous
- A machine can only process one job at a time
- Each job has to be performed on a set of machines in a pre-defined technological ordering
- Processing times are known ahead of time
- Each machine is continuously available for production
- No job splitting is allowed
- There is no job preemption on machines

Model Parameters and Variables

Input Parameters :

P_{ij} = the j^{th} sub-job of final product i. If $j = 0$, then it is the final assembly i.

P_{ijkm} = the k^{th} operation of sub-job j belonging to final product i, where the operation is performed on machine m.

N = number of final product orders to be satisfied ; $i = 1, \ldots, N$

M = number of machines available for production ; $m = 1, \ldots, M$

m_{ijk} = the machine required by the k^{th} operation of sub-job j belonging to final product i.

n_i = number of nodes or sub-jobs in the BOM for final product i.

O_{ij} = the set of operations required for processing one unit of P_{ij}.

H_{ij} = number of units of P_{ij} required for meeting the total demand of its direct parent job, if any exists.

$Z(P_{ij})$= the set of parents and grand parents for P_{ij}.

B_i = required batch size of final product i.

Q_i = quantity of P_{ij} required to meet demand.

$$Q_{ij} = B_i * H_{ij} \left(\prod_{P_{ik} \in Z(P_{ij})} H_{ik} \right) \quad \text{where} \prod_{P_{ik} \in Z(P_{ij})} H_{ik} \geq 1$$

System Variables :

S_{ijkm} = production start time of the k^{th} operation for P_{ij} on machine m.

t_{ijkm} = processing time per unit part required by the k^{th} operation of P_{ij} on machine m.

T_{ij} = total processing time required for making one unit of P_{ij}.

$$\left(T_{ij} = Q_{ij} \sum_{k=1}^{|0_{ij}|} t_{ijkm} \right)$$

F = production flow time (makespan).

α = large positive number

C_{ijkm} = production completion time of the k^{th} operation for P_{ij} on machine m.

Rt_{ijkm} = remaining path time for operations k of P_{ij} on m to realize the final product

$$Rt_{ijkm} = Q_{ij} \sum_{k'=k}^{|0_{ij}|} t_{ijk'm} + \sum_{\forall Z(P_{ij})} T_{ij}$$

$X_{ijkqrsm}$ = 1, if P_{ijk} proceed P_{qrs} on machine m
= 0, otherwise

Model Formulation

The model developed in this study is then formulated as follows:

$$Z_{MILP} = Min\ F \quad (1)$$
$$C_{i(j-1)km} - S_{ij1m'} \leq 0, \quad \forall i,j \quad (2)$$
$$C_{ij(k-1)m} - S_{ijkm'} \leq 0, \quad \forall i,j,k \quad (3)$$
$$C_{i0Km} - F \leq 0, \quad \forall i \quad (4)$$
$$C_{ijkm} - S_{ijkm} = t_{ijkm} * Q_{ij}, \quad \forall i,j,k \quad (5)$$
$$C_{qrsm} - C_{ijkm} + \alpha(1 - X_{ijkqrsm}) \geq t_{qrsm} * Q_{qr}, \quad \forall i,j,k,q,r,s \quad (6)$$
$$C_{ijkm} - C_{qrsm} + \alpha(X_{ijkqrsm}) \geq t_{ijkm} * Q_{ij}, \quad \forall i,j,k,q,r,s \quad (7)$$
$$X_{ijkqrsm} \in \{0, 1\}, \ integer, \quad \forall i,j,k \quad (8)$$
$$Q_{ij} \geq 1, \ integer, \quad \forall i,j \quad (9)$$

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The objective is to minimize the total tme necessary to process all the assemblies. Constraint (2) states that the completion time of the last operation (k) for $P_{i(j-1)}$ on machine m has to be less than or equal to the start time of the first operation ($k=1$) for P_{ij} on machine m' (provided that P_{ij} is the direct parent of $P_{i(j-1)}$ and $m' = m_{ijk}$. Constraint (3) expresses the operation relationship, while constraint (4) states that the completion time of the K^{th} operation for P_{i0} on machine m has to be less than or equal to production flow time F if K is the last operation. Constraint (5) expresses the processing time, while expression (6) and (7) ensure that no two jobs can be processed simultaneously on the same machine. Expression (8) is the integrality requirement on $X_{ijkqrsm}$ and (9) express that all product batch sizes are integer.

SOLUTION METHODOLOGY

The goal of the solution methodology is to generate efficient optimal or near optimal solutions to problems of practical size. A way of accomplishing this is by fixing all of the 0-1 variables. Fixing these variables would cause the disjunctive constraints in the MILP formulation to be replaced with simple precedence constraints (consisting of start and completion times). Disjunctive constraints arise naturally in scheduling problems where jobs have to share a machine and the order in which they are to be processed is not specified. Replacing all of the disjunctive constraints causes a reduction in the size of the problem and thus making it easier to solve.

<u>Heuristic</u>

Step 1. Collect the data for all jobs to be scheduled

Step 2. Decompose each job into its individual sub-job and their operations

Step 3. Calculate all Rt_{ijkm}

Step 4. Group the operations according to machine assignment. If the jobs are to be processed on M machines, create M columns and label the head of each column accordingly. A column represents a machine. Within each column, create three sub-columns and label them P_{ijkm}, Rt_{ijkm} and t_{ijkm} respectively.

Step 5. Partition the operations into sub-levels within each column.

Step 6. On a column by column basis, arrange the operations (within each sub-level only) in non-increasing order of Rt_{ijkm}. In the event of a tie, the selection is arbitrary.

Step 7. On a column by column basis, within the lowest sub-level, consider each operation and its position relative to its parallel related operation (operation are considered to be parallel related if their individual paths lead to the same direct parent). If both operations are competing on the same machine, rearrange them according to shortest processing time order by swapping their positions if necessary. Otherwise their relative positions remain the same. When the ordering is completed, calculate the completion time.

Step 8. For the higher sub-level, rearrange the operations for sequencing according to the completion time of their respective predecessors. When the ordering is completed, calculate the completion time. Always check the current sub-level and the ones below to see if there are operations that can be moved ahead of another to fill machine idle time.

Step 9. Repeat step 8 for all remaining sub-levels and final level.

Step 10. For each machine (column) convert the operation assignments into simple precedence constraints consisting of completion and start time.

Step 11. Formulate the problem using the MILP formulation, but replace the disjunctive constraints with the equation in step 10.

Step 12. Solve the problem using a LP solver.

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