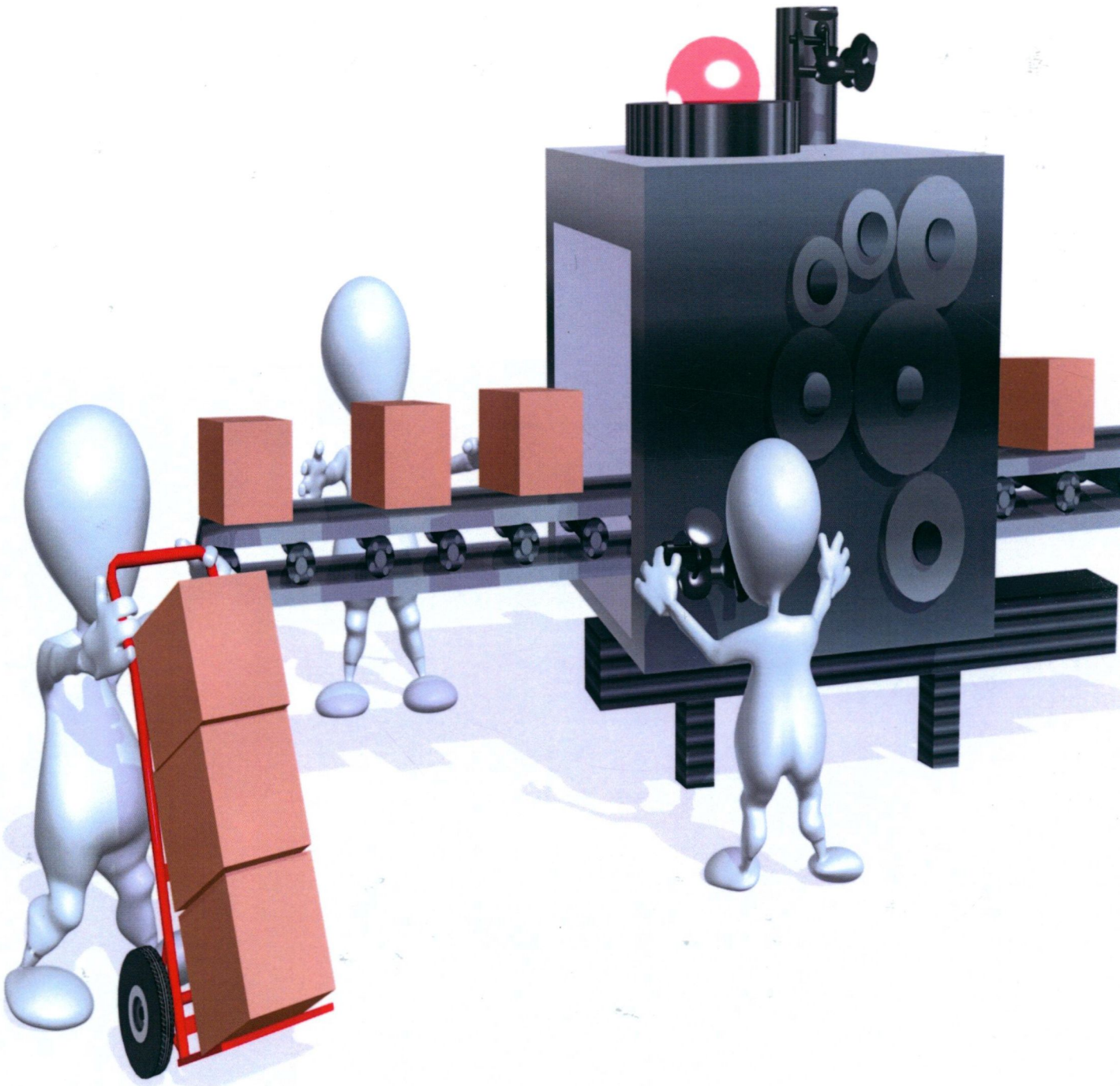
# Production And Operations Management: An Applied Modern Approach

Contributors: Marcello Fera, Fabio Fruggiero, et al.



## About the Book

In the recent years, organizations have started to put more emphasis on production as well as operations management. It is because of the increasing international competition and changing customer expectations. Due to these factors, organizations are endeavoring to improve their manufacturing operations. Operations management is satisfied as long as revenue is more than the cost. The modern operations management has realized that it is the value of products rather than the cost which is important. Apart from quality, revenue, and value, flexibility is also an important concern for operations managers. As far as operations management is concerned, flexibility is needed in customer demand, operation systems, and capacity. The induction of computers and advanced software has revolutionized operations management by increasing the flexibility of operations. Nowadays, everything is possible. Even the invention of high-tech machines will totally result to fast production. Lessening the span of time for manufacturing cycle will contribute to the speed and more production of goods. When a certain company offers products on similar quality and price, there will be fast distribution and purchase. As a result, the industry will have an edge over other firms. A business industry has its own set of strategies which are anchored with the available resources. For the inputs, materials, facilities, information, and customers are involved. Within the strategy, planning and designs are given attention. For the final output, good products and services are introduced to the market. With the prior knowledge for the upcoming trends in Operations management, even a small business firm can be at par with those large corporations. Success will not stay as a mere dream as long as a business owner adapt to modernization. In today's competitive environment, customer demands are very different from what they were just a few years ago. Customers, nowadays, demand lower cost, better quality, and greater speeds. Companies can achieve all these targets by managing their operations efficiently.

Production and Operations Management- An Applied Modern Approach includes theoretical and empirical insights to bridge the gap between academic and practical perspectives. It will act as a key point of reference for those wishing to conduct follow-on research into these operations management trends. Hence, in turn, this should enable operations management practices based in higher cost economies to compete more sustainably, on a long-term basis, with those located in lower cost economies.

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# Production And Operations Management: An Applied Modern Approach

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# Preface

In the recent years, organizations have started to put more emphasis on production as well as operations management. It is because of the increasing international competition and changing customer expectations. Due to these factors, organizations are endeavoring to improve their manufacturing operations. Operations management is satisfied as long as revenue is more than the cost. The modern operations management has realized that it is the value of products rather than the cost which is important. Apart from quality, revenue, and value, flexibility is also an important concern for operations managers. As far as operations management is concerned, flexibility is needed in customer demand, operation systems, and capacity. The induction of computers and advanced software has revolutionized operations management by increasing the flexibility of operations. Nowadays, everything is possible. Even the invention of high-tech machines will totally result to fast production. Lessening the span of time for manufacturing cycle will contribute to the speed and more production of goods. When a certain company offers products on similar quality and price, there will be fast distribution and purchase. As a result, the industry will have an edge over other firms. A business industry has its own set of strategies which are anchored with the available resources. For the inputs, materials, facilities, information, and customers are involved. Within the strategy, planning and designs are given attention. For the final output, good products and services are introduced to the market. With the prior knowledge for the upcoming trends in Operations management, even a small business firm can be at par with those large corporations. Success will not stay as a mere dream as long as a business owner adapt to modernization. In today's competitive environment, customer demands are very different from what they were just a few years ago. Customers, nowadays, demand lower cost, better quality, and greater speeds. Companies can achieve all these targets by managing their operations efficiently.

*Production and Operations Management- An Applied Modern Approach* includes theoretical and empirical insights to bridge the gap between academic and practical perspectives. It will act as a key point of reference for those wishing to conduct follow-on research into these operations management trends. Hence, in turn, this should enable operations management practices based in higher cost economies to compete more sustainably, on a long-term basis, with those located in lower cost economies.

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# 1

# PRODUCTION SCHEDULING APPROACHES FOR OPERATIONS MANAGEMENT

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## INTRODUCTION

Scheduling is essentially the short-term execution plan of a production planning model. Production scheduling consists of the activities performed in a manufacturing company in order to manage and control the execution of a production process. A schedule is an assignment problem that describes into details (in terms of minutes or seconds) which activities must be performed and how the factory's resources should be utilized to satisfy the plan. Detailed scheduling is essentially the problem of allocating machines to competing jobs over time, subject to the constraints. Each work center can process one job at a time and each machine can handle at most one task at a time. A scheduling problem, typically, assumes a fixed number of jobs and each job has its own parameters (i.e., tasks, the necessary sequential constraints, the time estimates for each operation and the required resources, no cancellations). All scheduling approaches require some estimate of how long it takes to perform the work. Scheduling affects, and is affected by, the shop floor organization. All scheduling changes can be projected over time enabling the identification and analysis of starting time, completion times, idle time of resources, lateness, etc....

A right scheduling plan can drive the forecast to anticipate completion date for each released part and to provide data for deciding what to work on next. Questions about "Can we do it?" and/or "How are we doing?" presume the existence of approaches for optimization. The aim of a scheduling study is, in general, to perform the tasks in order to comply with priority rules and to respond to strategy. An optimal short-term production planning model aims at gaining time and saving opportunities. It starts from the execution orders and it tries to allocate, in the best possible way, the production of the different items to the facilities. A good schedule starts from planning and springs from respecting resource conflicts, managing the release of jobs to a shop and optimizing completion time of all jobs. It defines the starting time of each task and determines whatever and how delivery promises can be met. The minimization of one or more objectives has to be accomplished (e.g., the number of jobs that are shipped late,

the minimization set up costs, the maximum completion time of jobs, maximization of throughput, etc.). Criteria could be ranked from applying simple rules to determine which job has to be processed next at which work-center (i.e., dispatching) or to the use of advanced optimizing methods that try to maximize the performance of the given environment. Fortunately many of these objectives are mutually supportive (e.g., reducing manufacturing lead time reduces work in process and increases probability to meeting due dates). To identify the exact sequence among a plethora of possible combinations, the final schedule needs to apply rules in order to quantify urgency of each order (e.g., assigned order's due date - defined as global exploited strategy; amount of processing that each order requires - generally the basis of a local visibility strategy). It's up to operations management to optimize the use of limited resources. Rules combined into heuristic[1] - approaches and, more in general, in upper level multi-objective methodologies (i.e., meta-heuristics[2] - ), become the only methods for scheduling when dimension and/or complexity of the problem is outstanding [1]. In the past few years, metaheuristics have received much attention from the hard optimization community as a powerful tool, since they have been demonstrating very promising results from experimentation and practices in many engineering areas. Therefore, many recent researches on scheduling problems focused on these techniques. Mathematical analyses of metaheuristics have been presented in literature [2, 3].

This research examines the main characteristics of the most promising meta-heuristic approaches for the general process of a Job Shop Scheduling Problems (i.e., JSSP). Being a NP complete and highly constrained problem, the resolution of the JSSP is recognized as a key point for the factory optimization process [4]. The chapter examines the soundness and key contributions of the 7 meta-heuristics (i.e., Genetics Approaches, Ants Colony Optimization, Bees Algorithm, Electromagnetic Like Algorithm, Simulating Annealing, Tabu Search and Neural Networks), those that improved the production scheduling vision. It reviews their accomplishments and it discusses the perspectives of each meta approach. The work represents a practitioner guide to the implementation of these meta-heuristics in scheduling job shop processes. It focuses on the logic, the parameters, representation schemata and operators they need.

## THE JOB SHOP SCHEDULING PROBLEM

The two key problems in production scheduling are "priorities" and "capacity". Wight (1974) described scheduling as "establishing the timing for performing a task" and observes that, in manufacturing firms, there are multiple types of scheduling, including the detailed scheduling of a shop order that shows when each operation must start and be completed [5]. Baker (1974) defined scheduling as "a plan than usually tells us when things are supposed to happen" [6]. Cox et al. (1992) defined detailed scheduling as "the actual assignment of starting and/or completion dates to operations or groups of operations to show when these must be done if the manufacturing order is to be completed on time"[7]. Pinedo (1995) listed a number of important surveys on production scheduling [8]. For Hopp and Spearman (1996) "scheduling is the allocation of shared resources over time to competing activities" [9]. Makowitz and Wein (2001) classified production scheduling problems based on attributes: the presence of setups, the presence of due dates, the type of products.

Practical scheduling problems, although more highly constrained, are high difficult to solve due to the number and variety of jobs, tasks and potentially conflicting goals. Recently, a lot of Advanced Production Scheduling tools arose into the market (e.g., Aspen PlantTM Scheduler family, Asprova, R2T – Resourse To Time, DS APS – DemandSolutions APS, DMS – Dynafact Manufacturing System, i68Group, ICRON-APS, JobPack, iFRP, Infor SCM, SchedulePro, Optiflow-Le, Production One APS, MQM – Machine Queue Management, MOM4, JDA software, Rob-ex, Schedlyzer, OMP Plus, MLS and MLP, Oracle Advanced Scheduling, Ortec Schedule, ORTEMS Productionscheduler, Outperform, AIMMS, Planet Together, Preactor, Quintiq, FactoryTalk Scheduler, SAP APO-PP/DS, and others). Each of these automatically reports graphs. Their goal is to drive the scheduling for assigned manufacturing processes. They implement rules and optimize an isolated sub-problem but none of the them will optimise a multi stage resource assignment and sequencing problem.

In a Job Shop (i.e., JS) problem a classic and most general factory environment, different tasks or operations must be performed to complete a job [10]; moreover, priorities and capacity problems are faced for different jobs, multiple tasks and different routes. In this contest, each job has its own individual flow pattern through assigned machines, each machine can process only one operation at a time and each operation can be processed by only one machine at a time. The purpose of the procedure is to obtain a schedule which aims to complete all jobs and, at the same time, to minimize (or maximize) the objective function. Mathematically, the JS Scheduling Problem (i.e., JSSP) can be characterized as a combinatorial optimization problem. It has been generally shown to be NP-hard[3] - belonging to the most intractable problems considered [4, 11, 12]. This means that the computation effort may grow too fast and there are not universal methods making it possible to solve all the cases effectively. Just to understand what

the technical term means, consider the single-machine sequencing problem with three jobs. How many ways of sequencing three jobs do exist? Only one of the three jobs could be in the first position, which leaves two candidates for the second position and only one for the last position. Therefore the no. of permutations is 3!. Thus, if we want to optimize, we need to consider six alternatives. This means that as the no. of jobs to be sequenced becomes larger (i.e., n>80), the no. of possible sequences become quite ominous and an exponential function dominates the amount of time required to find the optimal solution [13]. Scheduling, however, performs the definition of the optimal sequence of n jobs in m machines. If a set of n jobs is to be scheduled on m machines, there are $(n!)^m$ possible ways to schedule the job.

It has to undergo a discrete number of operations (i.e., tasks) on different resources (i.e., machines). Each product has a fixed route defined in the planning phase and following processing requirements (i.e., precedence constraints). Other constraints, e.g. zoning which binds the assignment of task to fixed resource, are also taken into consideration. Each machine can process only one operation at a time with no interruptions (pre-emption). The schedule we must derive aims to complete all jobs with minimization (maximization) of an objective function on the given production plant.

Let:

- $J = \{J_1, J_2, \ldots\ldots, J_n\}$ the set of the job order existing inside the system;
- $M = \{M_1, M_2, \ldots\ldots, M_m\}$ the set of machines that make up the system.

JSSP, marked as $\Pi_j$, consists in a finite set J of n jobs $\{J_i\}_{i=1}^{n}$. Each $J_i$ is characterized by a manufacturing cycle $CL_i$ regarded as a finite set M of m machines $\{M_k\}_{k=1}^{m}$ with an uninterrupted processing time $\tau_{ik}$. $J_i$, $\forall$ i = 1,…,n, is processed on a fixed machine $m_i$ and requires a chain of tasks $O_{i1}, O_{i2}, \ldots\ldots, O_{im_i}$, scheduled under precedence constraints. $O_{ik}$ is the task of job $J_i$ which has to be processed on machine $M_k$ for an uninterrupted processing time period $\tau_{ik}$ and no operations may pre-empted.

To accommodate extreme variability in different parts of a job shop, schedulers separate workloads in each work-centers rather than aggregating them [14]. Of more than 100 different rules proposed by researchers and applied by practitioners exist, some have become common in Operations Management systems: First come- First served, Shortest Processing Time, Earliest Due Date, Slack Time Remaining, Slack Time Remaining For each Operation, Critical Ratio, Operation Due Date, etc. [15]. Besides these, Makespan is often the performance feature in the study of resource allocation [16]. Makespan represents the time elapsed from the start of the first task to the end of the last task in schedule. The minimization of makespan arranges tasks in order to level the differences between the completion times of each work phase. It tries to smooth picks in work-center occupancy to obtain batching in load assignment per time. Although direct time constraints, such as minimization of processing time or earliest due date, are sufficient to optimize industrial scheduling problems, for the reasons as above the minimization of the makespan is preferable for general/global optimization performances because it enhances the overall efficiency in shop floor and reduces manufacturing lead time variability [17].

Thus, in JSSP optimization variant of $\Pi_j$, the objective of a scheduling problem is typically to assign the tasks to time intervals in order to minimize the makespan and referred to as:

$$C^*_{\max}(t) = f(CL_i, \tau_{ik}, s_{ik}), \forall\ i = 1 \ldots n; \forall\ k = 1 \ldots m \tag{1}$$

where t represent time (i.e. iteration steps)

$$C^*_{\max}(t) = \min(C_{\max}(t)) = \min\{\max_i [\tau_{ik} + s_{ik}] : \forall\ J_i \in J, \forall\ M_k \in M\} \tag{2}$$

and $s_{ik} \geq 0$ represents the starting time of k-th operation of i-th job. $s_{ik}$ is the time value that we would like to determinate in order to establish the suited schedule activities order.

## REPRESENTATION OF SCHEDULING INSTANCES

The possible representation of a JS problem could be done through a Gantt chart or through a Network representation.

Gantt (1916) created innovative charts for visualizing planned and actual production [18]. According to Cox et al. (1992), a Gantt chart is "the earliest and best known type of control chart especially designed to show graphically the relationship between planned performance and actual performance" [19]. Gantt designed his charts so that foremen or other supervisors could quickly know whether production was on schedule, ahead of schedule or behind schedule.

A Gantt chart, or bar chart as it is usually named, measures activities by the amount of time needed to complete them and use the space on the chart to represent the amount of the activity that should have been done in that time [7].

A Network representation was first introduced by Roy and Sussman [20]. The representation is based on "disjunctive graph model" [21]. This representation starts from the concept that a feasible and optimal solution of JSP can originate from a permutation of task's order. Tasks are defined in a network representation through a probabilistic model, observing the precedence constraints, characterized in a machine occupation matrix ***M*** and considering the processing time of each tasks, defined in a time occupation matrix ***T***.

$$M = \begin{pmatrix} M_{11} & \dots & M_{1n} \\ \vdots & \ddots & \vdots \\ M_{n1} & \dots & M_{nn} \end{pmatrix}; \; T = \begin{pmatrix} \tau(M_{11}) & \dots & \tau(M_{1n}) \\ \vdots & \ddots & \vdots \\ \tau(M_{n1}) & \dots & \tau(M_{nn}) \end{pmatrix}$$

JS processes are mathematically described as disjunctive graph G = (V, C, E). The descriptions and notations as follow are due to Adams et. al. [22], where:

- V is a set of nodes representing tasks of jobs. Two additional dummy tasks are to be considered: a source(0) node and a sink(*) node which stand respectively for the Source (S) task $\tau_0 = 0$, necessary to specify which job will be scheduled first, and an end fixed sink where schedule ends (T) $\tau^* = 0$;
- C is the set of conjunctive arcs or direct arcs that connect two consecutive tasks belonging to the same job chain. These represent technological sequences of machines for each job;
- $E = \bigcup_{r=1}^{m} D_r$, where $D_r$ is a set of disjunctive arcs or not-direct arcs representing pair of operations that must be performed on the same machine $M_r$.

Each job-tasks pair (i,j) is to be processed on a specified machine M(i,j) for T(i,j) time units, so each node of graph is weighted with j operation's processing time. In this representation all nodes are weighted with exception of source and sink node. This procedure makes always available feasible schedules which don't violate hard constraints [4] - . A graph representation of a simple instance of JSP, consisting of 9 operations partitioned into 3 jobs and 3 machines, is presented in fig. 1. Here the nodes correspond to operations numbered with consecutive ordinal values adding two fictitious additional ones: S = "source node" and T = "sink node". The processing time for each operation is the weighted value $\tau_{ij}$ attached to the corresponding node, v ∈ V, and for the special nodes, $\tau_0 = \tau^* = 0$.

Let $s_v$ be the starting time of an operation to a node v. By using the disjunctive graph notation, the JSPP can be formulated as a mathematical programming model as follows:

Minimize $s_*$ subject to:

$$s_w - s_v \geq \tau_v \; (v, w) \in C \tag{3}$$

$$s_v \geq 0 \mathrm{v} \in \mathrm{V} \tag{4}$$

$$s_w - s_v \geq \tau_v \vee s_v - s_w \geq \tau_w (\mathrm{v}, \; \mathrm{w}) \in D_{r,1} \leq r \leq m, \tag{5}$$

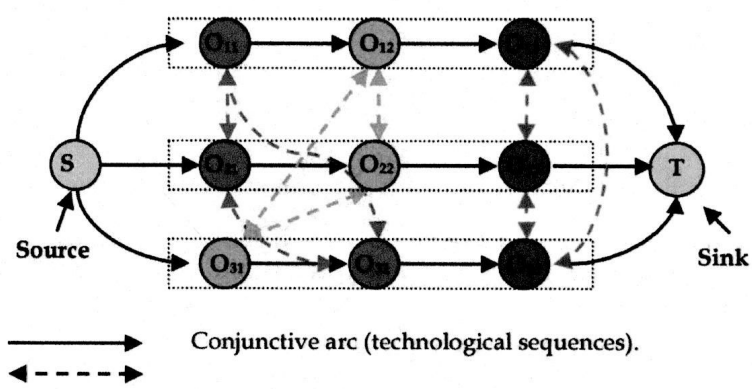


**Figure 1.** Disjunctive graph representation. There are disjunctive arcs between every pair of tasks that has to be processed on the same machine (dashed lines) and conjunctive arcs between every pair of tasks that are in the same job (dotted lines). Omitting processing time, the problem specification is O = {$o_{ij}$, (i,j) ∈ {1,2,3}²}, J = {$J_i$ = {$o_{ij}$}, (i,j) = 1,2,3}, M = {$M_j$ = {$o_{ij}$}, (i,j) = 1,2,3}. Job notation is used.

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