# Factory Model and Test Data Descriptions: OPIS Experiments 

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#### Abstract

This report defines a factory model and a set of experiments that can be used to compare alternative scheduling methods. The factory model defines parts, process plans, resources, and constraints. Multiple sets of test data are defined to test the scheduling algorithms under varying factory loadings. The model and test data are based on the ISIS/OPIS projects.


## 1 Introduction

The goal of this report is to define a factory model and a set of experiments that can be used to compare alternative scheduling methods. The model was originally created to provide a comparative analysis of the OPIS [4] [5] and ISIS [3] constraint directed scheduling systems and the COVERT dispatch rule[1]. The model is a simplification of the model used originally to test ISIS [2].

This report defines a Job Shop in terms of:

- Parts, including physical characteristics.
- Process plans composed of operations, precedence relations, and resource requirements.
- Resource descriptions, including labor machine ratios.
- Constraints covering due dates, work in process, machine restrictions, etc.

Twenty-two experiments are defined each containing orders composed of release dates, due dates, parts, quantity, and priority. Orders were statistically generated based on the parameters described in the latter sections.

The data described in this report is available online by sending email to Mark.Fox@cs.cmu.edu.

## 2 Model Overview

The factory being modeled is a Turbine Component Plant. A turbine blade is a complex three dimensional object composed of two parts: root and airfoil. The root is designed to clamp the blade into the turbine shaft and the airfoil is to transform the kinetic energy of hot stream or air traveling on it into the rotational motion of the turbine. A blade as in figure 1 is produced by a sequence of forging, milling, grinding and finishing operations to tolerances of a thousandth of an inch. There are three types of blades: $t$ blade, cse blade, and sse blade. (Short for T-shape, Curved Side Entry, and Straight Side Entry blades.) They differ in the operations and materials required to produce them.


Figure 1: A Turbine Blade

The three product families are further divided into six different products, Figure 2 shows the jobshop used in the tests and the three routes an order for a product could follow through the shop. This environment and the three routes are simplifications of the actual jobshop. The simplifications were made by extracting three of the most popular families of products and omitting linear portions of the original routings for each family. For the operations in the remaining routings, the actual estimates of operation times and machine setup times were retained. This model jobshop was tested to make sure that the locations of bottlenecks corresponded to the actual jobshop experience.

The resources in the model are located in separate work-areas. Work-areas consist of one or more identical machines or work-stations. For example, WA1 in Figure 2 is made up of 12 workstations. When an order arrives at WA1 for processing, any of these work-stations may be selected for the job. Machines or work-stations may only process one order at a time and no operation on an order may start until its preceding operation has ended.

The three product families are further divided into six different products, two products per family. Each family has its own set of alternative routes through the shop, as shown in Figure 2. Where a route forks, a choice has to be made as to which work-area the order should be routed to next. Notice that orders follow an acyclic path through the shop. The routes are represented as an operations graph for each product family. Additional information in the graphs includes processing time and setup time for each operation. Whenever a machine is assigned to perform a different operation from the one that it has most recently performed, or is scheduled to start for the first time, it must be appropriately setup with the right tools, fixtures, etc. The machine must remain idle for the duration of the setup.

The processing times required for each operation in producing each product may place different demands on the capacity of the work-areas. When these demands exceed the available capacity of a machine, that machine becomes a bottleneck. For the set of products and orders defined in our experiments, the bottleneck work-areas are WA2, WA3, WA4, WA5 and WA6.

The size of an order is the number of units to be produced, and this number is drawn from a uniform distribution, $\mathrm{U}(100,150)$ units. An order may also be assigned to one of six priority classes with equal probability of being in each class:

- Forced outages (FO): Orders to replace blades which malfunctioned during operation. It is important to ship these orders as soon as possible, no matter what the cost.
- Critical replacement (CR) and Ship Direct (SD): Orders to replace blades during scheduled maintenance. Advance warning is provided, but the blades must arrive on time.
- Service and shop orders (SO, SH): Orders for new turbines. Lead times of up to three years may be known.
- Stock orders (ST): Order for blades to be placed in stock for future needs.


## 3 Factory Model

### 3.1 Parts

Each part is a blade product defined by a blade type, process plan and length of its airfoil as in Table 1.


Figure 2: Jobshop Model

| part | blade type | process plan | air-foil length |
| :--- | :--- | :--- | ---: |
| Pblade1 | CSE blade | produce-Pblade1 | 26 |
| Pblade2 | SSE blade | produce-Pblade2 | 26 |
| Pblade3 | T blade | produce-Pblade3 | 26 |
| Pblade4 | CSE blade | produce-Pblade4 | 26 |
| Pblade5 | SSE blade | produce-Pblade5 | 26 |
| Pblade6 | T blade | produce-Pblade6 | 26 |

Table 1: Parts in OPIS Factory Model

### 3.2 Process Plans

There exists more than one way to produce a part in the factory. Consequently, a part's process plan is represented as a directed graph of operations. Nodes in the graph represent operations, and arcs represent precedence relations. Any path through the graph represents a "legal" process plan for the part. In the following operation schemata, the actual duration and resource needed for each operation are described for each part.

### 3.2.1 Process plan for Produce-Pblade1:

Table 2 is the process plan for Produce-Pblade1 with the operation name, operation type, machine working area, the previous operation and next operation in the process sequence. Op-1.bladel is the first operation in the process plan for Pbladel, therefore it does not have any previous operation. Then, this operation is followed by either of the two alternative rooting operation: op-2a.bladel or op-2b.blade2. The rest of the operations are op-3.blade1, op-4.blade1, op-5.blade1 and op-6.blade1. The last operation op-6.bladel has no next operation.

| operation | type | area | prev-operation | next-operation |
| :--- | :--- | :--- | :--- | ---: |
| op-1.blade1 | ws-operation | 1st.str | N/A | (or op-2a.bladel |
|  |  |  |  | op-2b.blade1) |
| op-2a.blade1 | rooting | elb.a.proc | op-1.blade1 | op-3.blade1 |
| op-2b.blade1 | rooting | rooting area | op-1.blade1 | op-3.blade1 |
| op-3.blade1 | ws-operation | 2nd/peg.str | (or op-2a.blade1 | op-4.blade1 |
|  |  | op-2b.blade1) |  |  |
| op-4.blade1 | airfoil | airfoil-area | op-3.blade1 | op-5.bladel |
| op-5.blade1 | ws-operation | brozing area | op-4.blade1 | op-6.blade1 |
| op-6.blade1 | ws-operation | final.str | op-5.bladel | N/A |

Table 2: Process Plan For Produce-Pblade1
There is different time duration for each operation in the process plan. In Table 3, two kinds of duration information are listed for each operation: setup time and piece time. Setups are needed when two successive operations on any particular machine are not of the same product family. Piece time is the processing time per piece for the required operation. Setup time and piece time are measured in seconds.

Process plans for the other blade parts in the following subsections have same columns as the above tables.

| operation | set-up | piece |
| :--- | :--- | ---: |
| op-1.blade1 | 25200 | 1238 |
| op-2a.blade1 | 49500 | 471 |
| op-2b.blade1 | 59400 | 759 |
| op-3.blade1 | 9000 | 1123 |
| op-4.blade1 | 5400 | 162 |
| op-5.blade1 | 10800 | 860 |
| op-6.blade1 | 14400 | 658 |

Table 3: Time Table for Produce-Pblade1

### 3.2.2 Process plan for Produce-Pblade2:

Table 4 and 5 are the process plan and its time table for producing Produce-Pblade2, respectively.

| operation | type | area | prev-operation | next-operation |
| :--- | :--- | :--- | :--- | ---: |
| op-1.blade2 | ws-operation | lst.str | N/A | (or op-2a.blade2 |
| op-2a.blade2 | rooting | root.210 | op-1.blade2 | op-2b-blade2) |
| op-3.blade2 |  |  |  |  |
| op-2b.blade2 | rooting | root.208h | op-1.blade2 | op-3.blade2 |
| op-3.blade2 | ws-operation | tapered-blade- | (or op-2a.blade2 | op-4.blade2 |
| op-4.blade2 | airfoil | area | airfoil-area | op-2b.blade2) |
| op-3.blade2 |  |  |  |  |
| op-5.blade2 | ws-operation | brazing area | op-4.blade2 | op-5.blade2 |
| op-6.blade2 | ws-operation | final.str | op-5.blade2 | op-6.blade2 |
| op/A |  |  |  |  |

Table 4: Process Plan For Produce-Pblade2

| operation | set-up | piece |
| :--- | :--- | ---: |
| op-1.blade2 | 25200 | 957 |
| op-2a.blade2 | 55800 | 2995 |
| op-2a.blade2 | 55800 | 2995 |
| op-3.blade2 | 16019 | 396 |
| op-4.blade2 | 5400 | 205 |
| op-5.blade2 | 10800 | 619 |
| op-6.blade2 | 14400 | 468 |

Table 5: Time Table for Produce-Pblade2

### 3.2.3 Process plan for Produce-Pblade3:

Table 6 and 7 are the process plan and its time table for producing Produce-Pblade3, respectively.

| operation | type | area | prev-operation | next-operation |
| :--- | :--- | :--- | :--- | ---: |
| op-1.blade3 | ws-operation | 1st.str | $\mathrm{N} / \mathrm{A}$ | (or op-2a.blade3 <br> op-2b.blade3) <br> op-2a.blade3 |
| rooting | root.208h | op-1.blade3 | op-3.blade3 |  |
| op-2b.blade3 | rooting | root.208v | op-1.blade3 | op-3.blade3 |
| op-3.blade3 | ws-operation | final.str | or op-2a.blade3 <br> op-2b.blade3) | N/A |

Table 6: Process Plan for Produce-Pblade3

| operation | set-up | piece |
| :--- | ---: | ---: |
| op-1.blade3 | 18000 | 356 |
| op-2a.blade3 | 54000 | 2818 |
| op-2b.blade3 | 54000 | 2818 |
| op-3.blade3 | 25200 | 345 |

Table 7: Time table for Produce-Blade3

### 3.2.4 Process plan for Produce-Pblade4:

Table 8 and 9 are the process plan and its time table for producing Produce-Pblade4, respectively.

| operation | type | area | prev-operation | next-operation |
| :--- | :--- | :--- | :--- | ---: |
| op-1.blade4 | ws-operation | 1st.str | $\mathrm{N} / \mathrm{A}$ | (or op-2a.blade4 |
|  |  |  |  | op-2b.blade4) |
| op-2a.blade4 | rooting | elb.a.proc | op-1.blade4 | op-3.blade4 |
| op-2b.blade4 | rooting | rooting.area | op-1.blade4 | op-3.blade4 |
| op-3.blade4 | ws-operation | 2nd/peg.str | (or op-2a.blade4 | op-4.blade4 |
|  |  |  | op-2b.blade4) |  |
| op-4.blade4 | airfoil | airfoil-area | op-3.blade4 | op-5.blade4 |
| op-5.blade4 | ws-operation | brazing area | op-4.blade4 | op-6.blade4 |
| op-6.blade4 | ws-operation | final.str | op-5.blade4 | N/A |

Table 8: Process Plan for Produce-Pblade 4

| operation | set-up | piece |
| :--- | :--- | ---: |
| op-1.blade4 | 25200 | 1238 |
| op-2a.blade4 | 49500 | 471 |
| op-2b.blade4 | 59400 | 759 |
| op-3.blade4 | 9000 | 1123 |
| op-4.blade4 | 5400 | 162 |
| op-5.blade4 | 10800 | 860 |
| op-6.blade4 | 14400 | 658 |

Table 9: Time Table for Produce-Pblade 4

### 3.2.5 Process plan for Produce-Pblade5:

Table 10 and 11 are the process plan and its time table for producing Produce-Pblade5, respectively.

| operation | type | area | prev-operation | next-operation |
| :--- | :--- | :--- | :--- | ---: |
| op-1.blade5 | ws-operation | 1st.str | $\mathrm{N} / \mathrm{A}$ | (or op-2a.blade5 |
|  |  |  |  | op-2b.blade5) |
| op-2a.blade5 | rooting | root.210 | op-1.blade5 | op-3.blade5 |
| op-2b.blade5 | rooting | root.208h | op-1.blade5 | op-3.blade5 |
| op-3.blade5 | ws-operation | tapered-blade- | (or op-2a.blade5 | op-4.blade5 |
|  |  | area | op-2b.blade5) |  |
| op-4.blade5 | airfoil | p/w | op-3.blade5 | op-5.blade5 |
| op-5.blade5 | ws-operation | brazing area | op-4.blade5 | op-6.blade5 |
| op-6.blade5 | ws-operation | final.str | op-5.blade5 | N/A |

Table 10: Process Plan for Produce-Pblade 5

| operation | set-up | piece |
| :--- | :--- | ---: |
| op-1.blade5 | 25200 | 957 |
| op-2a.blade5 | 55800 | 2995 |
| op-2a.blade5 | 55800 | 2995 |
| op-3.blade5 | 16019 | 396 |
| op-4.blade5 | 5400 | 205 |
| op-5.blade5 | 10800 | 619 |
| op-6.blade5 | 14400 | 468 |

Table 11: Time Table for Produce-Pblade 5

### 3.2.6 Process plan for Produce-Pblade6:

Table 12 and 13 are the process plan and its time table for producing Produce-Pblade6, respectively.

| operation | type | area | prev-operation | next-operation |
| :--- | :--- | :--- | :--- | ---: |
| op-1.blade6 | ws-operation | 1st.str | N/A | (or op-2a.blade6 |
| op-2a.blade6 | rooting | root.208h | op-1.blade6 | op-2b.blade6) |
| op-2b.blade6 | rooting <br> op-3.blade6 <br> ws-operation | root.208v <br> final.str | op-1.blade6 <br> (or op-2a.blade6 <br> op-2b.blade6) | op-3.blade6 |
|  |  |  | N/A |  |

Table 12: Process Plan for Produce-Pblade6

| operation | set-up | piece |
| :--- | ---: | ---: |
| op-1.blade6 | 18000 | 356 |
| op-2a.blade6 | 54000 | 2818 |
| op-2b.blade6 | 54000 | 2818 |
| op-3.blade6 | 25200 | 345 |

Table 13: Time Table for Produce-Pblade6

### 3.3 Resource

Following are the machines used in the scheduling task with detailed descriptions of which resource area it belongs to, and preference constraints ${ }^{1}$ [See Table 14]. However, notice that there is an operation, straightening, that uses manual workstations only instead of automated machines.

### 3.4 Constraint

Constraints are generated automatically for different product type, and its priority class. Some are preferences which could be relaxed and some are hard constraints to be exactly satisfied.

One more point to mention here is that the two constraints we had here for the experiments are:

1. due-date-constraints: each priority class has its own due date constraint providing a utility which varied with how early or late an order was.
2. q -preference: it specifies preference for sequencing parts of similar type.

Also, there are several preferences attached with the machines [See Table 14]:

1. shift constraints: it is to confine the operation on the machine within a certain shift restriction.
2. length preference: a preference constraint with true utility 1.1 and false utility of 1.0 . This is to differentiate the length of a turbine blade they would work on.
3. lug preference: preference constraint with true utility 1.1 and false utility of 1.0 . This is to differentiate machines for the number of lugs on a turbine blade.

[^0]

Table 14: Machines in OPIS Factory Model

## 4 Experiments

The experiments were designed, primarily, to focus on three scheduling objectives:

- Minimize total tardiness cost of all orders.
- Minimize the total number of setups to be performed at each machine.
- Minimize the work-in-process time (wip) of orders.

Tardiness cost is computed based on the relative tardy costs per day late. Work-in-process time refers to the length of time an order remains in the shop, assuming that it enters the shop only when it is scheduled to begin processing, not when it is first released to the shop. ${ }^{2}$ Order release time refers to the earliest possible time an order may start.

The characteristics of the orders were varied by manipulating the following parameters.
Product Mix. The probability of an order being for a particular product type is a variable. Two probability distributions were used, PM1 and PM2, shown in the Table 15:

The probability distributions were designed so that the resulting loads on the bottleneck machines would be approximately equal. Products 1 and 4 take proportionately shorter time relative to available capacity than the other products, hence more of those orders would be processed in a fixed period of time.

Priority class. An order can be assigned to one of six priority classes with equal probability of being in each class, as in Table 16:

[^1]| Prod. Mix | Prod. 1 | Prod. 2 | Prod. 3 | Prod. 4 | Prod. 5 | Prod. 6 |
| :--- | :--- | :--- | :--- | :--- | :--- | ---: |
| PM1 | 0.34 | 0.08 | 0.08 | 0.34 | 0.08 | 0.08 |
| PM2 | 0.5 | 0.04 | 0.12 | 0.18 | 0.12 | 0.04 |

Table 15: Product Mix in OPIS Factory Model

| Priority class | Relative cost | Description |
| :--- | :--- | ---: |
| FO | 20 | Forced Out |
| CR | 16 | Critical Replacement |
| SD | 12 | Ship Direct |
| SO | 8 | Service Order |
| ST | 4 | Stock order |
| SH | 1 | Shop Order |

Table 16: Order Priority Class in OPIS Factory Model
Order Lead Time. The length of time between the earliest time at which an order may start and its due date. Two main methods of generating order lead times were tested. The first was derived from policies in the actual jobshop. The shop charged a premium for "rush" orders which thus had a higher tardiness cost weighting. At the other extreme, orders that were fed to other sister shops were used in large construction projects with very long lead times and were more negotiable. These had lower tardiness cost weightings attached. Therefore, lead times were correlated with priority class and so we used a different lead time distribution for the test data depending on the priority class of the order where $P$ is the average total processing time for an order. The uniform distributions used for determining orders lead times in each priority class are shown in Table 17. (including setup time). The second method of generating order lead times assumed that order lead times were independent of priority class. Hence, a single uniform distribution was used.

| Priority class | FO | CR | SD | SO SH ST |
| :--- | :--- | :--- | :--- | ---: |
| distribution | $\mathrm{U}(0,4 \mathrm{P})$ | $\mathrm{U}(0,6 \mathrm{P})$ | $\mathrm{U}(0,6.5 \mathrm{P})$ | $\mathrm{U}(0,8 \mathrm{P})$ |

Table 17: Order Lead time in OPIS Factory Model
Order Release Pattern. Each order is associated with an earliest time at which that order is released for processing in the shop. Release times or start times are similar to arrival time of jobs in the shop, but in our experiments the release times are known at the start of scheduling. Just as the arrival pattern is typically manipulated in scheduling experiments to detect the effects on performance, we tested three different patterns of order release - (i) daily releases of orders; (ii) weekly releases; and (iii) exponentially distributed intervals between releases. In the last case, we tested mean intervals of 3 days, $\operatorname{EXP}(3)$, and 7 days, $\operatorname{EXP}(7)$, between releases.

Batchsize. Orders are released in batches. Batchsizes were drawn from uniform distributions and were coordinated with the order release patterns to obtain loads of approximately $70 \%$ and $105 \%$ on the bottleneck machines assuming no setup times. Two of the earlier tests involving daily releases of orders had bottleneck loads of 120 of lead times were sufficiently long to keep the number
of tardy orders low.

### 4.1 Experiment Generation Parameters

This section summarizes the different parameter settings for generating the order sets. Each parameter setting creates an order set belonging to a particular order category, which is identified by a number in the Category column. 22 order sets were created covering 18 categories. Two order sets were created for certain categories. The load of the shop was affected by the product mix, order release pattern times and batchsize together. The order lead time distribution was the strongest influence over the tardiness factor of the schedule [6]. The tardiness factor is a coarse measure of the proportion of tardy jobs in a random schedule. The four variables were manipulated to examine how the three systems would perform under varying conditions of our model shop. Two of the tests are comprised of 85 orders. All others have 120 orders [See Table 18].

| Category | Product mix | Batchsize | Release | Leadtime | Approx. Load |
| :--- | :--- | :--- | :--- | :--- | ---: |
| 1 | PM1 | $\mathrm{U}(0,8)$ | Daily | $\mathrm{U}(0,4 \mathrm{P} . .20 \mathrm{P})$ | $120 \%$ |
| 2 | PM1 | $\mathrm{U}(0,8)$ | Daily | $\mathrm{U}(0,4 \mathrm{P} . .8 \mathrm{P})$ | $120 \%$ |
| 3 | PM2 | $\mathrm{U}(0,15)$ | Exp(3) | $\mathrm{U}(0,4 \mathrm{P} . .8 \mathrm{P})$ | $105 \%$ |
| 4 | PM2 | $\mathrm{U}(0,15)$ | Exp(3) | $\mathrm{U}(0.67 \mathrm{P}, 5 \mathrm{P})$ | $105 \%$ |
| 5 | PM1 | $\mathrm{U}(0,29)$ | Weekly | $\mathrm{U}(0,4 \mathrm{P} . .8 \mathrm{P})$ | $90 \%$ |
| 6 | PM2 | $\mathrm{U}(0,29)$ | Weekly | $\mathrm{U}(0,4 \mathrm{P} . .8 \mathrm{P})$ | $90 \%$ |
| 7 | PM2 | $\mathrm{U}(0,29)$ | Weekly | $\mathrm{U}(0,4 \mathrm{P})$ | $90 \%$ |
| 8 | PM1 | $\mathrm{U}(0,29)$ | Weekly | $\mathrm{U}(0,4 \mathrm{P})$ | $90 \%$ |
| 9 | PM1 | $\mathrm{U}(0,29)$ | Exp(7) | $\mathrm{U}(0,4 \mathrm{P} . .8 \mathrm{P})$ | $90 \%$ |
| 10 | PM1 | $\mathrm{U}(0,29)$ | Exp(7) | $\mathrm{U}(0.67 \mathrm{P}, 5 \mathrm{P})$ | $90 \%$ |
| 11 | PM2 | $\mathrm{U}(0,11)$ | Exp(3) | $\mathrm{U}(0,4 \mathrm{P} . .8 \mathrm{P})$ | $77 \%$ |
| 12 | PM2 | $\mathrm{U}(0,11)$ | Exp(3) | $\mathrm{U}(0.67 \mathrm{P}, 5 \mathrm{sP})$ | $77 \%$ |
| 13 | PM1 | $\mathrm{U}(0,22)$ | Weekly | $\mathrm{U}(0,4 \mathrm{P} . .8 \mathrm{P})$ | $70 \%$ |
| 14 | PM2 | $\mathrm{U}(0,22)$ | Weekly | $\mathrm{U}(0,4 \mathrm{P} . .8 \mathrm{P})$ | $70 \%$ |
| 15 | PM1 | $\mathrm{U}(0,22)$ | Weekly | $\mathrm{U}(0.67 \mathrm{P}, 5 \mathrm{P})$ | $70 \%$ |
| 16 | PM2 | $\mathrm{U}(0,22)$ | Weekly | $\mathrm{U}(0.67 \mathrm{P}, 5 \mathrm{P})$ | $70 \%$ |
| 17 | PM1 | $\mathrm{U}(0,22)$ | Exp(7) | $\mathrm{U}(0,4 \mathrm{P} . .8 \mathrm{P})$ | $70 \%$ |
| 18 | PM1 | $\mathrm{U}(0,22)$ | Exp(7) | $\mathrm{U}(0.67 \mathrm{P}, 5 \mathrm{P})$ | $70 \%$ |

Table 18: Experiment Generator by Categories

### 4.2 Experiments

This section defines each experiment. The 22 experiments relate to each of the categories defined earlier as in Table 19:

The order generator would take input in the order.init file ${ }^{3}$ as in the following program example:

```
(weekly-orders 120 ; total number of lots
    "2/18/85 8:00:00" ; start & Date of first batch, Monk Day 8 a.m.
    '(FO CR SD SO SH ST) ; acceptable priority classes
        1 ; lead time factor
        29 ; max, batch size => mean size = 4 orders
    ,(50 54 66 84 96 100) ; 50:4:12: 18:12:4
)
```

[^2]The experiment files thus generated are listed in the sequence of test series in the following subsections. Each order has its associated lot number, lot name, priority class, manufacturing start quantity, requested schedule date and requested due date.

| Category | Test-series |
| :--- | ---: |
| 1 | 1 |
| 2 | 2,3 |
| 3 | 9 |
| $\mathbf{4}$ | 17 |
| 5 | 6 |
| 6 | 5 |
| 7 | 13,21 |
| 8 | 14,22 |
| 9 | 10 |
| 10 | 18 |
| 11 | 8 |
| $\mathbf{1 2}$ | 16 |
| 13 | 7 |
| $\mathbf{1 4}$ | 4 |
| 15 | 15 |
| 16 | 20 |
| 17 | 11 |
| 18 | 19 |

Table 19: Test-Series In OPIS Experiment











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## References

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[6] V. Srinivasan. A hybrid algorithm for the one machine sequencing problem to minimize total tardiness. Naval Research Logistics Quarterly, 18:317-327, 1971.


[^0]:    1/usr/isis/3/db/6.new/Winston-model/ws-instance/resources/ws-mach.l

[^1]:    ${ }^{2}$ This is generalizable to the case where the order has to enter the shop (say, in the form of raw materials) some constant period of time before processing starts.

[^2]:    ${ }^{3}$ file /test-series6/orders-db/order.init under the directory/usr/isis/3/isis-test/pso-exps

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