THE IMPACT OF LOT SIZING ON QUEUING DELAYS AN EDUCATIONAL SOFTWARE TOOL[1]

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ABSTRACT: It is now widely accepted that both large and small lot sizes can cause long lead times and consequently bad customer service in terms of late deliveries. The impact of the lot size on the lead time consists of a convex relationship, implying an optimal lot size minimising average lead time. In order to educate people with this undoubtedly correct, but yet controversial issue, we developed an educational software tool which helps to clarify the important determinants and allows for self-tuition experimentation. Therefore, in the first section we explain why this phenomenon is so important and how it can be applied in practice. In the second section, we introduce a small example and explain the theoretical foundations of the model. The third section describes the graphical user interface.

ACLIPS: A CAPACITY AND LEAD TIME INTEGRATED PROCEDURE FOR SCHEDULING

Aclips is a general hierarchical procedure for job shop planning and scheduling developed by Lambrecht, Ivens and Vandaele. [Lambrecht, Ivens and Vandaele, 1998] The procedure consists of four phases. The first phase includes a lot sizing decision and a lead time approximation phase. In the second phase, the tuning phase, management can intervene to obtain acceptable product lead times. The third phase deals with scheduling and therefore includes manufacturing order grouping, release date setting and detailed scheduling. Finally in the execution phase, the schedules are transferred to the shop floor and are executed. This four-phase hierarchical approach is illustrated in Figure 1.

Lot Sizing Phase

There is a convex relationship between lot size and lead time. Three main effects influence lead times: batching, congestion and stochasticity. Large lot sizes lead to long lead times because it ties up resources for long periods of time. This effect is called the batching effect. On the other hand, due to frequent setups, small manufacturing lot sizes cause a lot of lost machine time. As a consequence, utilisation and thus the total lead time increases. [Karmarkar, 1987] In addition, variability of both arrival, production and setup times has a substantial influence on lead times. In steady state, increasing variability will always increase average lead times and thus work-in-process levels. [Hopp and Spearman, 1996]

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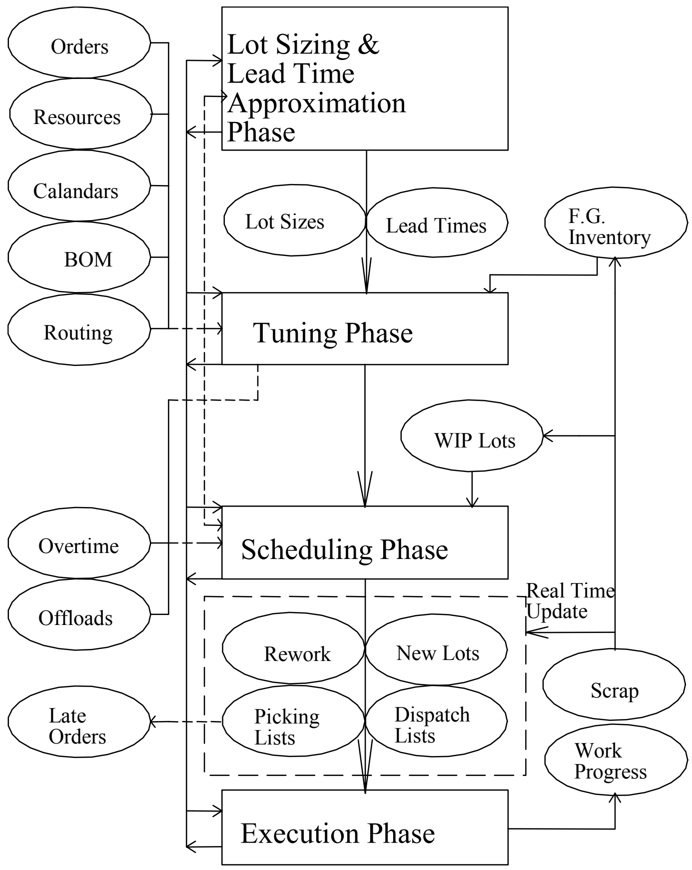

Figure 1. The four-phase hierarchical approach of ACLIPS

The goal of the lot sizing phase is to take into account the batching, the congestion and the variability effects on the total lead time and to determine an optimal lot size that minimises the total product lead time.

For each product, the average and the variance on the total lead time and a postulated probability distribution (lognormal) make it possible to estimate of the lead time to obtain a given customer service (lead time percentile). The technical details can be found in Vandaele. [Vandaele, 1996]

Tuning Phase

In this phase management has a lot of opportunities to remedy long and unacceptable lead times. As it is not the focus of this paper, for further details we refer to other papers. [Vandaele, Lambrecht, De Schuyter and Cremmery, 1999]

Scheduling Phase

In this phase the customer orders are grouped into manufacturing orders, release date for the manufacturing orders are obtained and finally the grouped manufacturing orders are scheduled in detail. From this phase, the determination of the release date assumes knowledge of the total characterisation of the product lead time: the release date is the due date minus a lead time percentile (based on a predetermined customer service level). Subsequently a detailed schedule is worked out. All operations are scheduled within their respective time windows, while simultaneously many constraints have to be taken into account: limited availability of resources, the sequence of operations, etc.

Execution Phase

In this phase, the work is released to the shop floor and a foollow up system delivers the necessary feed back for the planning and scheduling system ACLIPS.

AN EXAMPLE

We demonstrate the software using a small example.

Data Input

Our small company produces two products: product P and product S in a job shop-like environment. The work floor contains three machines: a cutter, a grinder and a lathe. Product P first visits the cutter, then the grinder and finally the lathe. Product S faces two operations: one on the lathe and a second on the grinder. The customer orders for the next month are summarised in Table 1 and Table 2. The operations are given table 3, all numbers expressed in hours.

TABLE 1
Orders for Product P

Order	Quantity	Arrival Date (days)	Interarrival Time (days)
1	1	8	8
2	5	14	6
3	3	23	9
4	2	27	4
5	4	30	3

TABLE 2
Orders for Product S

Order	Quantity	Arrival Date (days)	Interarrival Time (days)
1	1	3	3
2	3	4	1
3	2	5	1
4	3	8	3
5	1	10	2
6	1	12	2
7	3	13	1
8	2	16	3
9	3	19	3
10	1	20	1
11	2	21	1
12	3	22	1
13	3	25	3
14	1	28	3
15	1	30	2

TABLE 3
Shop Characteristics for Both Products

	Operation	Machine	Setup Average	Setup Variance	Processing Average	Processing Variance
Product P	1	Cutter	20	0	30	0
	2	Grinder	20	400	10	100
	3	Lathe	24	0	12	0
Product S	1	Lathe	16	0	8	0
	2	Grinder	20	400	10	100

The order data for the products are summarised in the average demand quantity per order, the average and the variance (and squared coefficient of variation) of the order interarrival time. All this is summarised in Table 4.

TABLE 4
Summarised Data for Both Products

	Product P	Product S
Average Demand Quantity	3	2
Variance	3744	493,7
Mean	144	48
SCV	0,180555555	0,214285714

The data must be entered as follows:

- Machine names and their descriptions must be entered in the 'Input: Machine' window.
- Order names, average demand, interarrival time and SCV are entered in the 'Input: Orders' window.
- The 'Input: Sequence' window enables to define a routing for each product.
- The setup time, setup variance, unit processing time and unit processing time variance must be entered in the 'Input: Routing' window.

When all data are entered, the software optimises the average lead times in terms of the individual lot sizes.

Output

After a successful optimisation, the output is displayed in two windows.

The first window, 'Output: Resources', displays the value of the objective function and all information about the machines as can be seen in Table 5. 'Wait Time' is the average time that a product will have to wait before it can be processed on the machine. 'Scaint' stands for squared coefficient of variation of internal arrivals. The utilisation, 'Util.' of a machine is the percentage of available time that a machine is being used (setup and processing). 'Var Wait' is the variance of the waiting time. As can be seen, the grinder is the bottleneck, which leads to longer waiting times.

The second window, 'Output: Orders', shows the output results that are order-specific.
The results for product P can be found in Tables 6, 7 and 8.

TABLE 5
Model Output for Each Machine

	Machine Name	Wait Time	Scaint	Util.(%)	Var Wait
1	Cutter	6,2936	0,134	72,8094	150,7229
2	Grinder	110,6698	0,3068	87,1142	17947,7258
3	Lathe	41,7046	0,3259	82,1485	2949,9277

TABLE 6
Total Lead Time for Product P (in Hours)

Optimal Lot Size	4,0416
Collection Time	72,9985
Expected Total Lead Time	505,8299
Standard Deviation Lead Time	159,4661

Product P is best produced in batches of 4 units. This leads to a minimal product lead time of 506 hours. Because orders do not arrive in exact batches of 4 units, some orders will have to wait before they can be produced in terms of the optimal lot size. This waiting time is represented by 'Collection Time'. The other entries are straightforward.

TABLE 7
Lead Time Percentiles for Product P

80 %	90 %	95 %	99 %
626,1	716,3	800,5	988,1

To obtain a service level of 80%, the manufacturer will have to quote a lead time of at least 626 hours. This is larger than the average lead time namely 506 hours. The difference between the percentile and the average is called the safety time, in this case we need a 120 hours safety time to obtain a 80% customer service level. It is clear that the higher the service level, the more safety time is needed.

TABLE 8
Detailed Lead Time Information for Product P

	Machine	Waiting Time	Setup Time	Processing Time
1	Cutter	6,2936	20	121,2481
2	Grinder	110,6698	20	40,416
3	Lathe	41,7046	24	48,4993

Table 8 shows all the operations for product P as specified in the routing. 'Waiting Time' is the time that the product spends in the queue before the machine is set up and processing can start. The 'Setup Time' is the time needed to set up the machine. 'Processing Time' is the time needed to process the entire batch. Note that the sum of the collection time, the waiting times, the setup times and the processing times equals the expected total lead time. The analysis of product S is analogous.

THE GRAPHICAL USER INTERFACE

In this section we give a brief overview of the software along the lines of the help file.

The program is designed to let you enter your data (machines, order groups and sequences) as easily as possible. ACLIPS stands for 'A Capacity and Lead Time Integrated Procedure for Scheduling'. ACLIPS minimises the total lead time by calculating the optimal lot sizes for each order type and is built for educational purposes only.

Input Machines

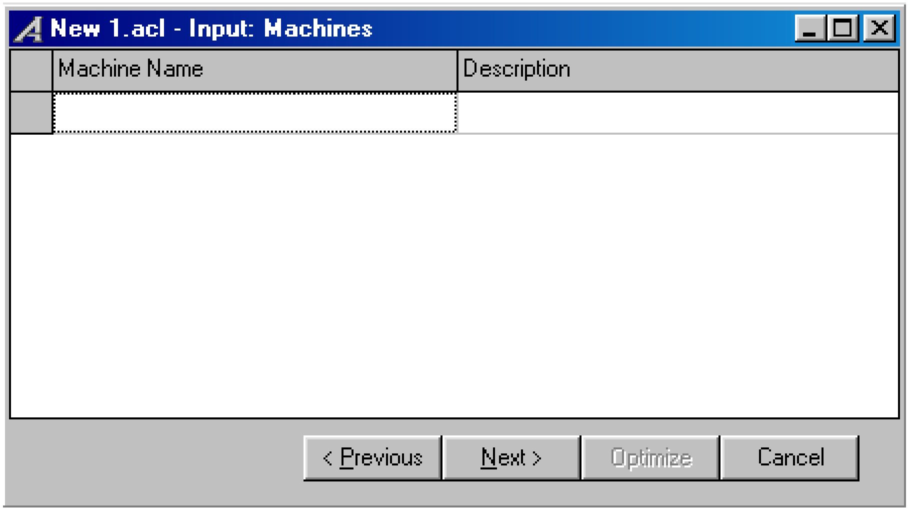

Figure 1. 'Input Machines' window

This window (Figure 1) enables you to insert your machines, and a description. Note that a name is required. A description is only for comment or additional machine information, and is therefore not obligatory. You can insert new machines by typing in the empty bottom line, or by hitting the 'insert' button. A new empty line is inserted right above the selected machine. Hitting 'delete' allows you to delete a machine. You are asked for confirmation, because deleting a machine is irreversible. When a machine is in use (e.g. you have already combined some orders and machines, and you've decided to delete a machine) you are informed about it when asked for confirmation. When a used machine is deleted, all operations (combination of machine and order) containing that machine are deleted! Before proceeding, all machines are checked: no empty names are allowed, as well as no double used names: all machines must have a unique name. You can use the description to distinguish one machine from another, should the situation require identical names. Please note that 'machine 1' and 'MACHINE 1' are considered to be identical. When all these requirements are met, you can proceed with inserting order groups by clicking the Next-button.

Input Orders

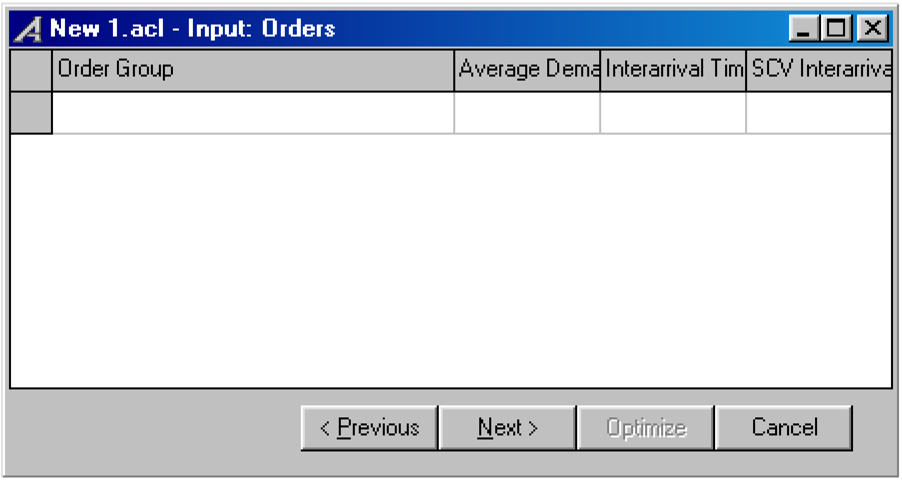

Figure 2. 'Input Orders' window

Here (Figure 2) you can enter the order groups. Single orders can not be entered. Orders have to be entered as order streams, patterns, with their average demand, average interarrival time and interarrival time SCV. Here, all fields are mandatory. If any field has a invalid content, you are not able to proceed until you have corrected it (e.g. empty name or a non-numeric value where a numeric value is required.) 'Demand' and 'Interarrival Time' must be strictly larger than zero, SCV must be positive. Inserting and deleting orders is similar to inserting and deleting machines. Now that all machines and order groups have been entered, you can proceed with the sequence part by clicking on the Next-button.

Input Sequence

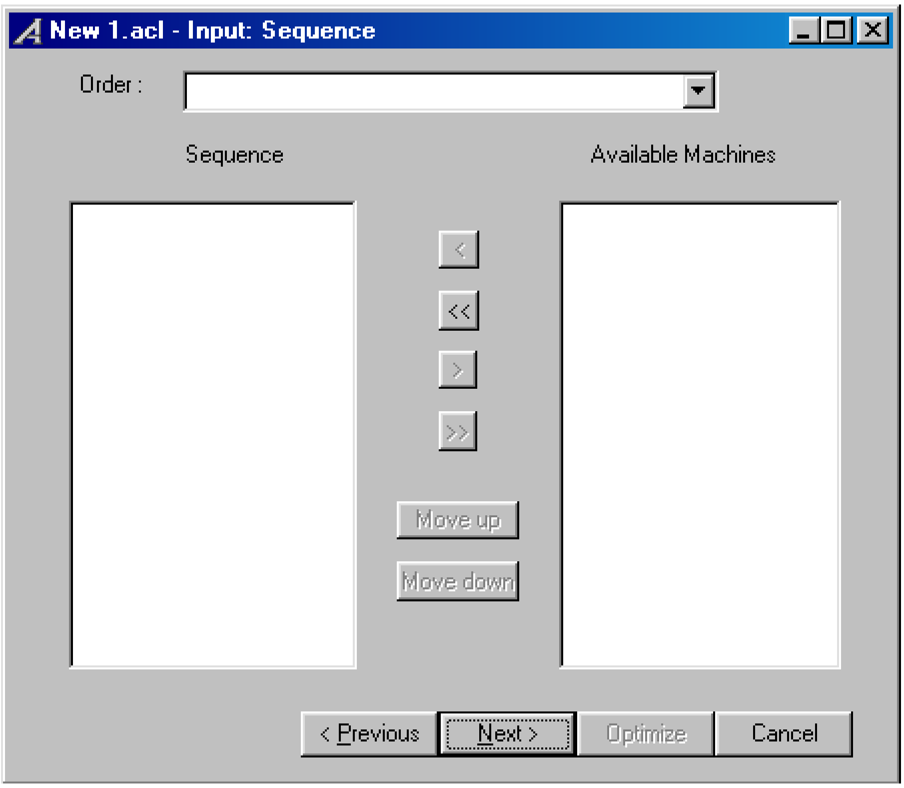

Figure 3. 'Input Sequence' window

This (Figure 3) is a crucial window in the input process: here you can combine the order groups and the machines into operations. First select the order you want to edit. The 'Sequence list' shows you what machines are used in what sequence to produce the order. Machines are selected from the 'Available machines' list. When for an order all the available machines must be used, simply click the 'add all' (<<) button. When only one machine must be added, click the 'add' (<) button. If you add a machine and a machine is selected in the sequence list, the machine is inserted right before that selected machine. If no machine is selected, the new machine is inserted at the end of the sequence list.

You can easily remove one or all the machines from the sequence list by making use of the 'remove' (>) and the 'remove all' (>>) buttons. The machine is removed only for that particular order. The 'move up' and the 'move down' buttons allow you to change the sequence of machines. The next step in the process concerns the routing.

Input Routing

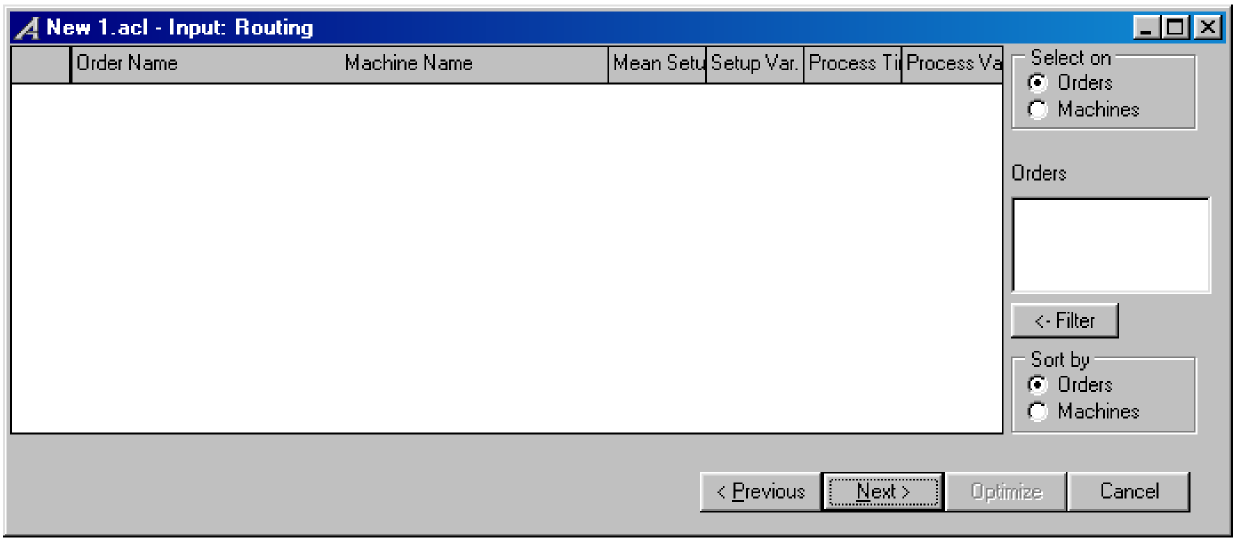

Figure 4. 'Input Routing' window

You can see (Figure 4) an overview of all the operations you have entered. An operation is a combination of an order and a machine. An order consists of one or more operations, all of which need a setup time and processing time on a particular machine. For every operation, four numeric variables have to be entered: setup time average and variance, and the process time average and variance.

You can check your routing by means of the buttons on the right. You can select one or more machines or orders. Hold the <ctrl> key and click on the order or machine in the right listbox to select more than one machine or order. The results are shown when you click 'Filter'. Your problem is now ready for optimization.

Saving the Problem

When you save your problem, the file is stored in the acl-format (ACLIPS Project File).
You can easily view the file with an editor, or even with Microsoft Excel, since the data are stored as ASCII text, with a <tab> to separate the fields. Please do not change these files because you may not be able to open the file anymore with ACLIPS. You can open and print the acl-files, or use them in a text, but they are not meant to insert your data. You should enter your problem data using the

ACLIPS program itself. Now that your problem has been saved (and all necessary data have been entered) you can optimise it.

Optimisation

While optimising your problem, the program proceeds with an input check along the following lines:

- Correct machine names
- Correct order names and values
- All machines are used at least once
- All orders have at least one operation
- All routing values must be correct:
  - Variances, setup time and processing time cannot be negative
  - At least one setup time must differ from zero
  - If setup time is zero then corresponding setup variance must also be zero
- All machine utilisations must be less than 100 %.

When all controls are successfully executed, the optimisation starts. The program then jumps to the output analysis (Figure 5 and 6).

Output: Resources

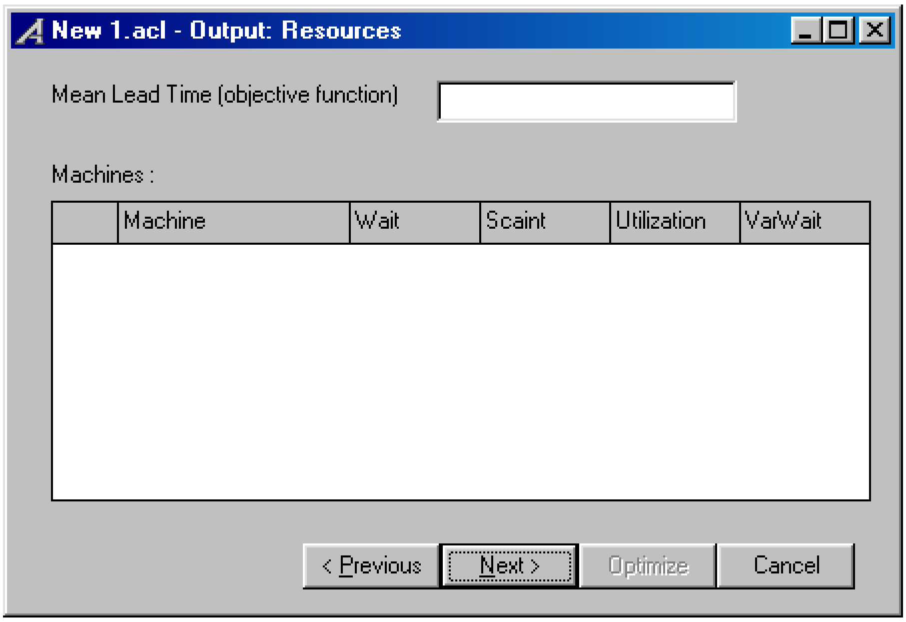

Figure 5. ‘Output Resources’ window

After optimisation the program prepares several output data. The mean lead time is the objective function value at the optimum. Subsequently, for each machine the waiting time (‘Wait’), the SCV of internal arrivals (‘Scaint’), the ‘Utilization’ and the variance of the waiting time (‘VarWait’) are shown.

Orders and Operations

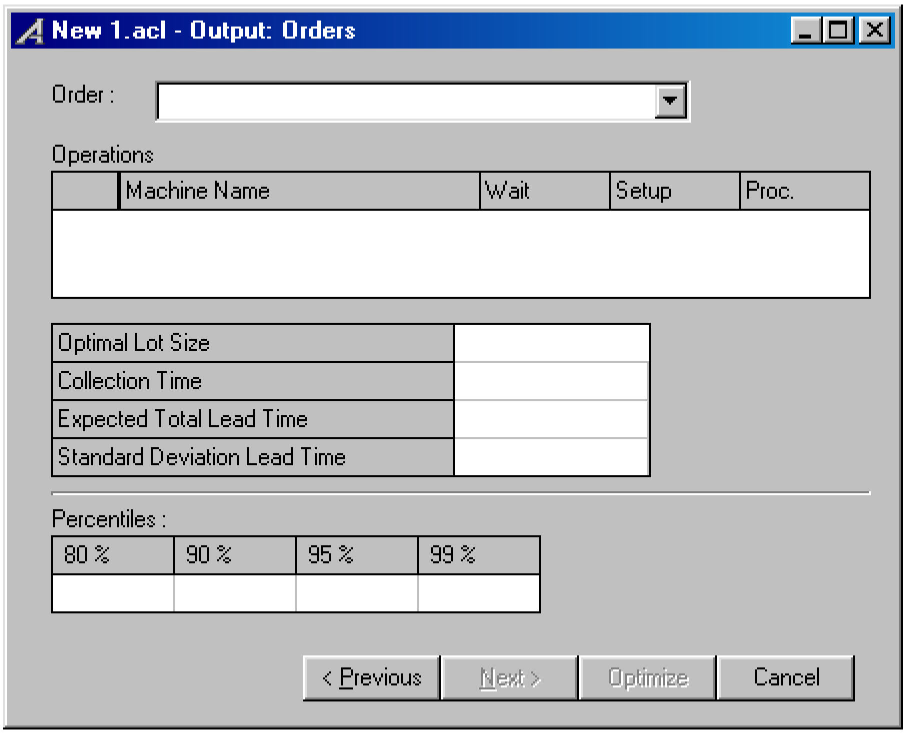

Figure 6. 'Output Orders' window

For the selected order, the operations are listed, together with their waiting time, setup time and processing time. The optimal lot size, the collection time, expected total lead time and its standard deviation are shown in the middle grid. The lower grid gives you information on percentiles: if you want to have a certain customer service percentage, you will have to quote a delivery time of at least the corresponding value.

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