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Amendment of Heuts-Selen's Lotsizing and Sequencing Heuristic for Single Stage Process Manufacturing Systems

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Abstract

This paper suggests an improvement procedure for Heuts-Selen's (HS) lotsizing and sequencing heuristic for single stage process manufacturing systems. Potential savings are considerable to incorporate the additional routine in the heuristic. The proposed procedure attempts to minimize the "hidden inventories" caused by the original heuristic without reducing its computational efficiency. A brief literature review is provided before discussion of the amendment. Further ways of extending the heuristic are suggested in this paper.

1. INTRODUCTION

The study discussed in this paper is a part of a general investigation of productivity improvement for process manufacturing systems. The typical process industry manufacturer produces a variety of non-differentiable commodities such as foods, drugs, petroleum, cleaning products, fertilizers, paint, etc. which may be sold in bulk for industrial purposes or smaller packages for consumer use. In general, process industries are capital expensive when compared to discrete type of manufacturing systems.

Process industries when compared to discrete manufacturers, have been slow to embrace the planning techniques developed during the last 30 years. Almost half of all manufacturers are process oriented, however, given our experiences, only 15-20 percent of all manufacturing planning and control systems have been installed in process industries (see also Taylor (1979) , Koene (1988), and Buxey (1989)). More recently special attention is given to this matter. Among many other reasons, we believe the trends in globalization forces many process (chemical) industries to combine their activities and improve the use of their resources by better planning and control procedures in order to be competitive. Without an effective means of production planning and control, it is clear that no reasonable economic returns can be expected from these type of industries.

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Lotsizing and sequencing is receiving increasing attention in the process industries. In order to highlight its importance, in section 2 we briefly describe the hierarchical planning pertain to these environments. In section 2 we also present an overview of the related literature. The paper continues in section 3 with a discussion on the mathematical model for the joint lotsizing and sequencing problem and its complexity. In section 4, the HS-heuristic is discussed. Section 5 describes the amendment procedure and section 6 presents a computational example. Finally section 7 draws some conclusions.

2. PLANNING HIERARCHIES IN PROCESS INDUSTRIES

The hierarchical planning in process industries is slightly different from discrete industries (see Ashayeri and De Paepe (1990)), Taylor (1979), and Taylor et al. (1981). Three levels of hierarchy can be distinguished as follows (see figure 1):

1. Strategic Level

This stage is defined as the product / plant selection stage. In many process industries there are alternative sites capable of producing the same product, as such it is important to decide where which products should be produced. The criteria for the selection of the best alternative is to maximize the use of facilities at lowest cost (costs of production and distribution). Optimization tools are found most useful for this stage. However in practice, these decisions are made arbitrary based on intuition.

2. Tactical Level

Given a selected set of products and allocation, for each plant, it is necessary to maximize the use of resources (raw materials and facilities) at lowest costs. Of the important problems addressed at this level we can refer to optimizing product blends, determining target safety stocks, developing aggregate production plan, and determining lotsizes and storage requirements. Many process industries are concerned with developing a minimum cost blend of ingredients which meets product specifications. Optimization has been implemented more frequently for blending problems. Some process industries have to produce products to stock and, as a results, have a large finished good inventory to buffer the plant from demand variations. Statistical techniques are useful to size safety stocks but in practice this decisions are based on rules of thumbs and not much attention is paid to statistical techniques.

Developing aggregate plan and determining lotsizes and storage requirements (intermediate or final storage) are important activities which are usually performed at a tactical level. A combination of optimization and heuristic can provide good solution for these problems. However, in practice, again rules of thumbs are the means of aggregate planning, lotsizing, and storage requirements determination.

3. Operational Level

In general, at this stage attention is paid to performance of the system. The aim would be to minimize switch-over times by proper sequencing. Manual planning is practiced in many process manufacturing industries. In the first place "natural" sequencing (see Taylor (1987)) is used where, one tries subsequently to keep the production run long enough whenever the setup time is large. At this level optimization has failed when applied to the real life problem situations, since in many instances the size of problem is large which results in increased computation time beyond realistic bounds. Simulation has been frequently used at this level to verify the impact of manually derived alternative sequences. No need to demonstrate that simulation is not the right tool for screening alternative sets of decisions.

To conclude, in process industries no consistent and rational planning and control system can be found to tackle all three planning levels in relation to MRPII in discrete industries. One of the major problems with the use of MRPII in such environments is the nature of production (e.g. recipe changes as a result of changes in raw material used, input/output imbalance due to evaporation, etc., capacity and technical constraints). In this regard Taylor and Bolander (1988) suggest a process flow scheduling which can replace MRP. Our industrial experiences show that optimization is very useful for problems of the type explained at level 1 or blending at level 2. In many cases lotsizing and sequencing are not separable. This makes the situation even more complex. As such simple heuristic procedures are required to handle both lotsizing and sequencing problems.

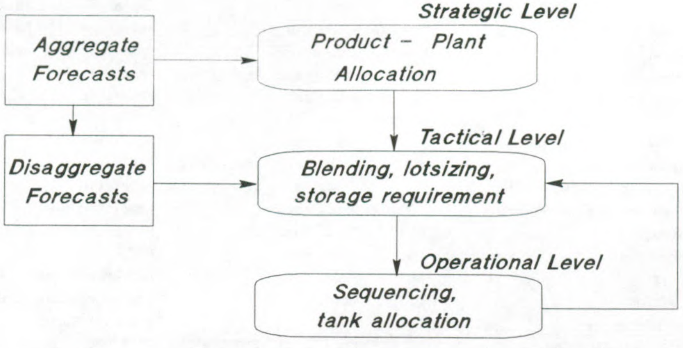


Figure 1: Hierarchical planning in process industries

Overview of the literature in process industries

Most reported literature on lotsizing and sequencing have tackled the problems separately. Few authors have developed a combined optimization-heuristic procedure for the joint problem but most of these procedures were limited or developed according to demand of a specific user. Despite the fact that procedures may not always be case dependent, the inherent assumptions made reduced the possibility of having a generalized procedure. Table 1 presents some of the work done in this area. A comparative study of two lotsizing-sequencing heuristics can be found in Heuts et al. (1992).

3. JOINT LOT SIZING-SEQUENCING MODEL

The problem to be analyzed has the following characteristics:

- Multiple products are manufactured on a single bottleneck machine (reactor), after which they are stored in pre-assigned tanks with given capacities.

- The production takes place in batches. Because of chemical reaction properties, the reactor has to be completely filled each time when a batch of a product is processed. The batch size is assumed to be equal for each product.

- Switch-over-times (setup times) between batches of *different* products are very significant and highly sequence-dependent because of long cleaning operations between batches. Thus, the production sequence in each period is a decision variable.

- Switch-over times between production batches of the *same* product are relatively short but the cost is significant to be included. We will refer to these as internal switch-overs in contrast to the switch-over between different products which we call external switch-overs.

Ref. No.	Tackled issues	No. of Prod. Stages	Constraints	Solution Procedure
1	Scheduling	1	Prod. Cap.	Heuristic
2	Scheduling	2	Prod. Cap., Storage cap.	Heuristic
4	Lotsizing and sequencing	1	Prod. cap.	MIP, Heuristic
6	Scheduling	mixed	Prod. cap.	Heuristic
7	Lotsizing and Scheduling	1	Prod. cap.	Lagrangean Rex./B & B
8	Scheduling and Sequencing	m-serial	Prod. cap.	Heuristic (TSP based)
10	Scheduling	mixed	Prod. cap.	Optimization / Heuristic
11	Sequencing	2,	Prod. cap., Storage cap.	Heuristic
13	Sequencing	1, m parallel	Prod. cap.	Heuristic
14	Lotsizing and Sequencing	1	Prod. cap.	Heuristic
15	Scheduling and Sequencing	m	Prod. cap., Storage cap.	MIP
16	Lot-sizing and Sequencing	1	Prod. Cap., Storage cap.	Heuristic
17	Scheduling and Sequencing	m-serial	Prod. cap.	Heuristic
18	Scheduling	1	Prod. cap.	MIP/heuristic
19	Scheduling	1	Prod. cap.	MIP
24	Lotsizing	1	Prod. cap.	Lagrangean Rex./B & B
25	Lotsizing	1	Prod. cap.	Lagrangean Rex./B & B
26	Sequencing	2		Branch & Bound
27	Production Planning	1	Prod. cap., Storage cap.	Goal Programming

Table 1. Literature review on the joint lotsizing and sequencing problem

- For the bottleneck machine, the following is given:
  - the required production capacity per batch of a product,
  - the switch-over times, and
  - the total available production capacity over the horizon.

- Each product has a preassigned storage capacity, i.e. there is restriction on the sum of the beginning inventory and the production in every period for each product.

- The switch-over costs are considered as opportunity cost of lost machine hours on the bottleneck machine, because the capacity is tight and every hour lost results in lost production and sales.

- Inventory costs are calculated in relation to the quantity of each product carried over to the subsequent period.

- Production, switch-over and inventory costs are assumed to be constant over the entire horizon.

- For each product the customers' demand per period is given and must be satisfied. Demand is delivered at the end of a period.

The problem under consideration can be formulated mathematically as follows:

<u>Notations :</u>

Indices

i = product index;
j = product index;
t = period index;

Parameters

T	= number of periods in planning horizon;
A_i	= production time in hours for 1 batch of product i
S_{ij}	= switch-over time from product i to j in hours;
OC	= opportunity cost per machine hour;
I_{io}	= beginning inventory of product i in batches;
I_{iT}	= end inventory of product i in period T in batches
D_{it}	= demand for product i in period t in batches;
H_i	= inventory cost per batch per period of product i;
PC	= total available production capacity per period in hours;
TC_i	= tank capacity of product i in batches.

Decision Variables

X_{ijt}	= 1, if a switch-over from product i to j takes place in period t ;
	= 0, otherwise
Y_{it}	= production in batches of product i in period t;
I_{it}	= ending inventory of product i in period t, in batches.

The Model

$$\text{Min.} \sum_{t=1}^{T} \sum_{i=1}^{N} \sum_{j=1}^{N} X_{ijt} * S_{ij} * OC + \sum_{t=1}^{T} \sum_{i=1}^{N} \{ \max.(1, Y_{it}) - 1 \} * S_{ii} * OC$$

$$+ \sum_{t=1}^{T} \sum_{i=1}^{N} \{ I_{io} + \sum_{\tau=1}^{t} (Y_{i\tau} - D_{i\tau}) \} * H_i \tag{1}$$

$$\sum_{i=1, i \neq j}^{N} X_{ijt} \leq 1 \qquad j=1,\dots,N ; t=1,\dots,T \tag{2.1}$$

$$\sum_{j=1, j \neq i}^{N} X_{ijt} \leq 1 \qquad i=1,\dots,N ; t=1,\dots,T \tag{2.2}$$

$$Y_{it} \leq \{ \sum_{\tau=t}^{T} D_{i\tau} + I_{iT} \} * \{ \sum_{j=1, j \neq i}^{N} X_{ijt} \} \qquad i=1,\dots,N ; t=1,\dots,T \tag{3}$$

$$\sum_{i=1}^{N} \{ A_i * Y_{it} + [\max.(1, Y_{it}) - 1] * S_{ii} \} +$$

$$\sum_{i=1}^{N} \sum_{j=1, j \neq i}^{N} X_{ijt} * S_{ij} \leq PC \qquad t=1,\dots,T \tag{4}$$

$$I_{io} + \sum_{\tau=1}^{t} \{ Y_{i\tau} - D_{i\tau-1} \} \leq TC_i \qquad i=1,\ldots,N \; ; \; t=1,\ldots,T \qquad (5)$$

$$I_{io} + \sum_{\tau=1}^{t} \{ Y_{i\tau} - D_{i\tau} \} \geq 0 \qquad i=1,\ldots,N \; ; \; t=1,\ldots,T \qquad (6)$$

$$X_{ijt} \in \{ 0, 1 \} \qquad i \neq j; \; i=1,\ldots,N \; ; \; j=1,\ldots,N \; ; \; t=1,\ldots,T \qquad (7)$$

$$Y_{it} \quad \text{integer} \qquad i=1,\ldots,N \; ; \; t=1,\ldots,T \qquad (8)$$

The first term of the objective function represents the switch-over costs, the second term states the internal switching costs only. Production costs (like manpower, electricity, etc.) are not taken into account as they are the same under every possible feasible production plan. The third term indicates the inventory holding costs.

Note that the switch-over costs of the first product in each period are not taken into account (as they are directly dependent on the last produced product in the preceding period). Incorporating this aspect in the mathematical model would complicate the problem considerably, as the sequencing problem would not any more be limited to a single period. The HS-heuristic, which is discussed hereafter, incorporates the linkage among periods when performing the sequencing.

Constraint sets (2.1) and (2.2) ensure that in each period at most one external switch-over takes place from and to each product. Constraint set (3) guarantees that product i will only be produced whenever there is a switch-over for product i. These constraints are not complete since the switch-over for the first product is not considered in any period. Constraint set (4) represents the sum of production, internal and external switch-over times which may not exceed the available production capacity. Constraint set (5) represents the beginning inventory as well as the production of each period which should not surpass the storage capacity. Constraint set (6) avoids backlogging, which is not permitted.

4. THE HS-HEURISTIC FOR JOINT LOTSIZING AND SEQUENCING

In this section a global description of the Heuts-Selen heuristic will be given, a more detailed discussion on this heuristic can be found in [9] and [16]. HS-heuristic performs better for tight capacitated single bottleneck machine problems. The heuristic consists of two stages; an ***initialization*** stage and an *improvement* stage. The initialization stage consists of constructing an initial feasible production plan. In constructing such a plan the following shifting rules are considered :

- The production of a product is shifted to an earlier period whenever the product is already produced in that period (this rule is violated whenever there is no way of solving the tight capacity problem).
- The production capacity in the period to which shifting takes place should be sufficient.
- The tank capacity for the periods during which the shifted production is stored, needs to be sufficient.

A Global Description of the Initialization Procedure

The initialization procedure starts with demand modification for beginning inventories. The demand as well as the beginning inventories in practice are usually continuous quantities (tons). As production takes place in integer batches, the above result has to be rounded up. The so-called net demand per period forms a first production scheme. It can then be checked whether the tank capacity per product is sufficient to store these production quantities. When this is not the case, there is no feasible solution possible. To determine how much production capacity is required the sequencing routine is called for. When the production capacity is sufficient in all periods, then the initialization stage is ended. When this is not the case for a particular period (except the first one), a backward shifting procedure takes place.

The backward shifting procedure is implemented for a particular product to reduce the required machine capacity for that period. The product for which shifting is performed, is the product with the lowest inventory cost, provided that production of the product in the period to be shifted is already planned. In doing so, we consider the fact that the existing production capacity and tank capacity are sufficient in that period. Further, shifting is performed batch by batch until infeasibility is removed. After every shifting, the sequencing routine is called for, to calculate the resulting production capacity requirement. When there is no possibility of shifting to an earlier period where the same product is produced, it is checked whether shifting can be performed to periods where the product is not produced. If all this does not help, there is no feasible starting solution. When at the end of the initialization procedure still a machine capacity problem exist, this would call for modification of the order acceptance plan. Figure 2 provides a schematic view of the solution procedure. The dashed boxes represent the amendment procedure to be discussed in the next section. Details with regard to the improvement stage of the algorithm can be found in [9] and [16].

5. AMENDMENT PROCEDURE

In the original initialization stage batches may be shifted to earlier periods to solve bottleneck problems in certain periods. As a result inventories are created, which do not receive further consideration in the remainder of the HS-heuristic. It is obvious that savings can be realized by shifting forward the batches created in the initialization phase to periods where they originated from. The dashed block in figure 2 illustrates the amendment procedure. In order to perform this step, information regarding all the backward shifts are collected in the initialization stage (see the high lighted block in figure 2). The information list in this block consists of the following set of data:

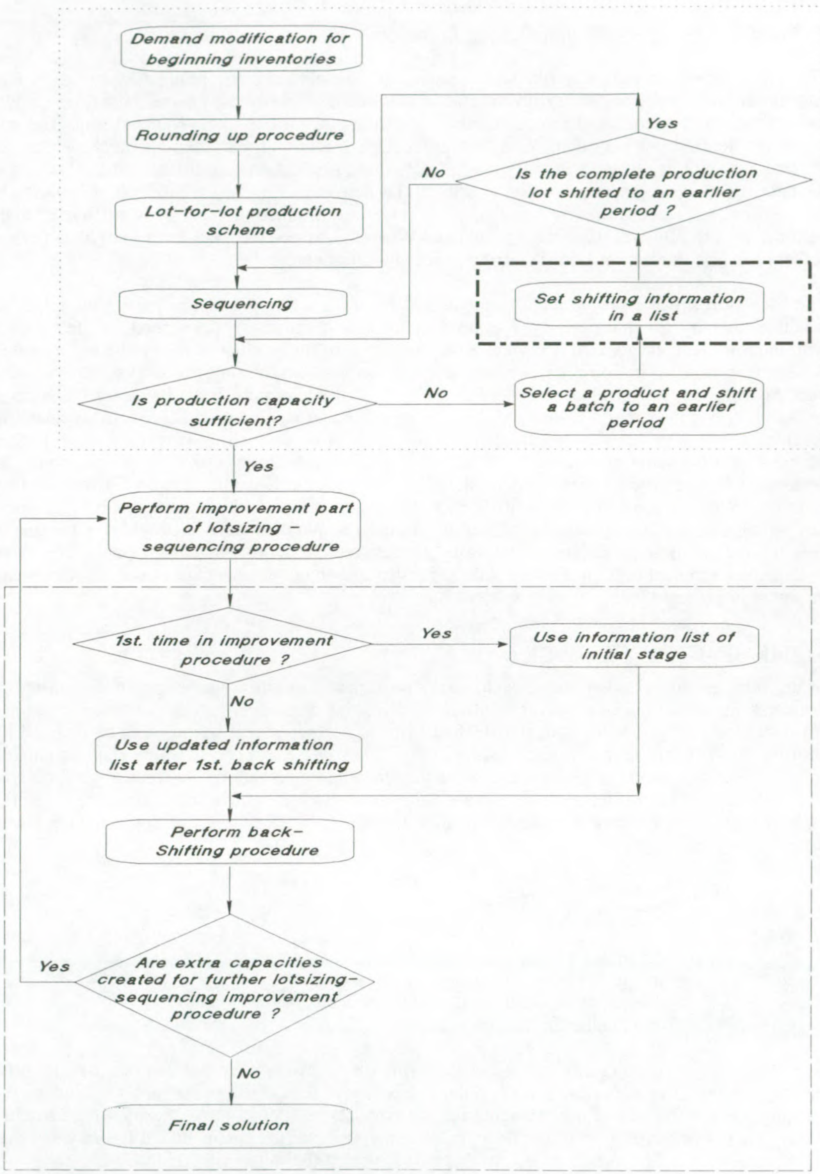
$(i_{product}, t_{from}, t_{to}, b_{number})$

where,

$i_{product}$ = the product number that is shifted
t_{from} = the period from which shifting takes place
t_{to} = the period to which shifting takes place
b_{number} = the number of batches that is shifted

A backward shifting procedure was developed which is relatively easy and can create substantial savings in the inventory costs with little computation time. In order not to hamper the computational efficiency of the HS-heuristic, we have chosen not to trace exactly where batches during the improvement part of the heuristic are moving to. This means that at the moment that we want to shift the batches forward, we have to look into the following possibilities:

a) the product is not produced any more in t_{from},
b) the product is not produced any more in t_{to}.

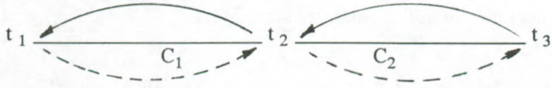


Dotted block shows the initial stage
Dashed block shows the amendment parts
High lighted block shows shifting information list

Figure 2 : HS-heuristic Solution Procedure

Case (a) means that the last period to which forward shifting takes place is max. $\{t \mid t \leq t_{from}\}$; whereas in case (b) the period from which forward shifting can take place is max. $\{t \mid t \leq t_{to}\}$.

We perform the forward shifting of the initialization inventories at the end of the lotsizing sequencing heuristic, as in this way it does not damage the existing heuristic and may create new shifting possibilities. The forward shifting starts with the last period of the horizon, such that forward shifting of batches does not form a blockage, as explained in the following example. Assume that in the initialization stage the following shifting took place:



Here, one batch of a product is shifted from period t_2 to t_1 with a corresponding capacity of C_1 and a shifting from t_3 to t_2 with capacity C_2. Assume now, that after lotsizing-sequencing, a production scheme results with the following Slack Production Capacity (SPC) information :

$$SPC_{t_3} > C_2 \text{ and } C_1 - C_2 \leq SPC_{t_2} \leq C_1$$

Starting from the last period of the horizon, first C_2 can be shifted forward from period t_2 to period t_3, such that it creates extra capacity in period t_2, and thus C_1 can also be shifted forward from t_1 to t_2. Such shifts are only feasible when also the tank storage capacities are sufficient. Notice that a negative SPC indicates a lack of capacity while a positive SPC shows left-over capacity.

6. COMPUTATIONAL EXAMPLE

The above procedure was implemented into the HS-heuristic and programmed in Turbo-Pascal 6 on a microcomputer. In this section the numerical example of Heuts and Selen (1990) is used to

	Product Number														
Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	6.4	4.2	3.6	6.8	3.6	4.6	2.7	4.2	5.5	7.6	4.6	3.8	9.1	2.7	2.2
2	6.4	4.4	5.6	8.8	5.6	5.6	2.4	2.4	6.4	7.6	4.6	3.6	6.5	2.9	2.4
3	6.4	4.6	6.2	8.8	4.7	5.6	2.6	2.5	5.5	7.6	4.6	3.3	6.5	2.9	2.6
4	8.0	4.3	5.1	7.9	7.0	5.5	4.2	2.9	4.8	8.0	4.8	5.3	8.4	3.9	3.0
5	6.4	2.7	4.9	7.3	5.5	4.2	3.0	2.6	5.5	7.6	4.6	3.6	6.5	3.5	3.0
6	6.4	2.8	4.3	6.5	6.4	2.4	3.2	2.8	5.5	8.2	4.6	3.6	6.5	3.6	3.2
7	8.4	3.0	4.7	6.5	6.5	2.4	3.4	3.0	6.4	8.3	4.6	3.9	6.5	3.8	3.4
8	6.4	8.1	5.3	6.5	5.5	2.4	3.6	2.6	5.5	8.4	4.6	4.0	6.5	4.2	3.5
9	8.5	3.9	6.0	7.3	8.2	3.0	4.5	3.7	6.2	9.3	6.0	5.1	7.0	5.4	4.8
10	8.4	5.3	7.2	6.4	6.4	2.4	4.2	3.2	5.5	8.9	4.6	4.1	6.5	4.7	3.5
I_o	0.0	0.0	0.0	450	0.0	50	0.0	0.0	350	0.0	0.0	0.0	0.0	0.0	100
Processing time / batch	4.0	6.0	4.0	2.0	4.0	2.4	3.4	6.0	4.0	4.0	2.0	4.0	2.0	3.6	3.2
Tank capacity	600	500	500	500	500	600	600	600	500	600	600	500	600	500	600

Table 2 : Demand (in batches) and Initial inventories; I_o, (in tons), Processing time (in hours), Tank capacity (in tons)

demonstrate the benefits of applying the amendment procedure discussed in the previous section. Table 2 illustrates the demand for 15 products over 10 periods. The bottom rows of the table indicate respectively the initial inventory of each product, the processing time per batch of 60 tons (the standard batch size for each product), and the tank capacity dedicated to each product.

For this problem the inventory holding costs are set at 1000 Guilders per batch per period and the opportunity costs for lost production are set at 20,000 Guilders per hour. The production capacity per period is 336 hours, i.e. two full weeks period or 14 days and three shifts per day (14 days * 24 hours). Other data required to implement the amended HS-heuristic procedure are the switch-over times. Table 3 presents the time required to switch over from one product to another, the diagonal line indicating internal switch-overs.

Prod. No.	Product Number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.5	2.0	6.6	8.0	7.6	3.1	3.7	8.0	6.3	8.0	6.6	5.9	5.6	6.9	2.0
2	2.4	0.5	3.6	8.0	8.0	4.3	2.5	3.2	3.8	3.3	5.6	2.2	3.3	5.1	2.0
3	6.1	5.1	0.5	3.8	8.0	2.0	2.3	2.0	6.3	7.8	5.6	7.1	2.0	3.4	8.0
4	5.0	8.0	2.0	0.5	6.7	3.1	8.0	5.4	5.1	6.1	2.0	8.0	8.0	2.0	3.3
5	7.4	2.1	4.8	8.0	0.5	2.8	7.9	6.8	2.7	8.0	5.3	5.8	4.6	6.7	2.8
6	6.0	2.5	8.0	2.0	4.1	0.5	2.0	2.8	8.0	5.4	5.4	5.8	5.8	6.2	8.0
7	2.1	2.0	2.6	4.8	2.0	8.0	0.5	3.2	3.8	8.0	4.4	8.0	6.7	7.5	5.9
8	6.6	3.1	8.0	4.5	6.7	2.7	5.1	0.5	7.9	8.0	2.8	2.4	3.8	2.0	7.4
9	4.6	8.0	6.5	5.6	5.2	3.6	6.1	7.8	0.5	2.7	8.0	4.8	5.7	4.4	4.9
10	2.0	2.6	8.0	5.8	8.0	8.0	2.5	5.4	8.0	0.5	8.0	7.8	2.1	8.0	8.0
11	2.0	4.6	4.9	5.5	4.5	4.9	2.0	2.1	4.8	5.8	0.5	7.0	8.0	6.0	2.0
12	5.2	3.0	5.2	7.0	8.0	8.0	2.0	6.9	8.0	7.5	4.4	0.5	8.0	3.1	5.9
13	3.5	8.0	5.0	8.0	4.8	4.4	4.4	7.6	8.0	2.5	6.2	2.4	0.5	3.3	5.2
14	2.0	5.3	3.9	8.0	5.2	4.6	6.4	5.1	2.0	6.2	2.2	2.1	8.0	0.5	2.5
15	7.6	8.0	8.0	8.0	8.0	3.0	4.8	4.2	3.5	2.0	4.5	2.0	2.0	2.0	0.5

Table 3 : Switch-over time matrix (in hours)

The first step in the initialization phase is to adjust the initial inventories. As a result, the effective requirement per period for each product is calculated. This information is summarized in table 4. The last two columns of this table represent the total required capacity per period and deviations of the available capacity per period. For example in period 1 up to 3 there are excess-capacities while in period 4 there is a lack of 11.70 hours. As such a number of batches are shifted to earlier periods to satisfy the capacity constraints. The results are as follows:

Product 1 from period 4 to period 3 : 3
Product 1 from period 8 to period 7 : 1
Product 1 from period 8 to period 6 : 2
Product 1 from period 9 to period 7 : 1
Product 1 from period 9 to period 6 : 7
Product 1 from period 9 to period 5 : 1
Product 1 from period 10 to period 7 : 1
Product 1 from period 10 to period 6 : 4
Product 4 from period 10 to period 8 : 1
Product 4 from period 10 to period 5 : 1
Product 4 from period 10 to period 2 : 1

	Product Number																
Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Cap. Req.	SPC
1	7	5	4	0	4	4	3	5	0	8	5	4	10	3	1	287.30	48.70
2	6	4	6	9	6	6	3	2	7	8	5	4	6	3	2	327.20	8.80
3	7	5	6	8	4	5	2	3	5	7	4	3	7	3	3	312.40	23.60
4	8	4	5	8	7	6	4	2	5	8	5	5	8	4	3	347.70	-11.70
5	6	3	5	8	6	4	3	3	5	8	5	4	6	3	3	309.40	26.60
6	6	2	4	6	6	3	4	3	6	8	4	4	7	4	3	304.50	31.50
7	9	3	5	7	7	2	3	3	6	8	5	4	6	4	4	331.40	4.60
8	6	9	5	6	5	2	4	2	6	9	4	4	7	4	3	345.10	- 9.10
9	9	3	6	7	8	3	4	4	6	9	6	5	7	5	5	375.50	-39.50
10	8	6	7	7	7	3	4	3	5	9	5	4	6	5	3	364.10	-28.10

Table 4 : Initial batch production , Required Capacity (in hours),
Slack production capacity (in hours) per period

Shifting the above batches results in the following feasible solution (see table 5). The cost of this production plan amounts to ***fl*** 12,567,933.

	Product Number																
Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Cap. Req.	SPC
1	8	5	4	0	4	4	3	5	0	8	5	4	10	3	1	291.80	44.20
2	7	4	6	10	6	6	3	2	7	8	5	4	6	3	2	334.20	1.80
3	12	5	6	8	4	5	2	3	5	7	4	3	7	3	3	334.90	1.10
4	5	4	5	8	7	6	4	2	5	8	5	5	8	4	3	334.20	1.80
5	11	3	5	9	6	4	3	3	5	8	5	4	6	3	3	334.40	1.60
6	13	2	4	6	6	3	4	3	6	8	4	4	7	4	3	336.00	0.00
7	10	3	5	7	7	2	3	3	6	8	5	4	6	4	4	335.90	0.10
8	3	9	5	7	5	2	4	2	6	9	4	4	7	4	3	334.10	1.90
9	0	3	6	7	8	3	4	4	6	9	6	5	7	5	5	334.10	1.90
10	3	6	7	4	7	3	4	3	5	9	5	4	6	5	3	332.20	3.80

Table 5 : First feasible production plan

At this stage the HS improvement heuristic comes into picture for constructing a cheaper production schema. The result of implementing the heuristic is given in table 6. This production plan costs ***fl*** 12,266,933, which provides a saving of ***fl*** 301,000. But the amendment procedure has not yet been fully implemented. Thus, there are still initial "hidden inventories" which can be saved by forward shifting. The shifts which can take place are:

Product 1 from period 6 to period 9 : 2
Product 1 from period 5 to period 9 : 1
Product 1 from period 7 to period 10 : 1
Product 1 from period 6 to period 10 : 3
Product 4 from period 8 to period 10 : 1
Product 4 from period 5 to period 10 : 1
Product 4 from period 2 to period 10 : 1

	Product Number															
Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Cap. Req.	SPC
1	8	5	4	0	4	4	6	5	0	8	10	8	10	3	1	334.00	2.00
2	7	4	6	10	6	11	0	2	12	8	0	0	6	3	2	326.70	9.30
3	12	5	6	8	4	0	2	3	0	7	9	8	7	3	3	332.50	3.50
4	5	4	5	8	7	15	7	2	5	8	0	0	8	4	3	332.10	3.90
5	11	5	5	9	6	0	0	3	5	8	9	4	6	3	3	335.50	0.50
6	13	0	4	6	6	0	4	3	12	8	0	4	7	4	3	328.00	8.00
7	10	3	5	7	7	0	3	5	0	8	9	4	6	4	4	325.30	10.70
8	3	12	5	7	5	5	4	0	6	9	0	4	7	4	3	333.90	2.10
9	0	0	6	7	8	0	4	4	6	9	6	9	7	5	5	322.90	13.10
10	3	6	7	4	7	3	4	3	5	9	5	0	6	5	3	313.40	22.60

Table 6 : HS-heuristic solution structure

The above shifts result in a new production plan given in table 7. The total cost of realizing such a plan is ***fl*** 12,234,933, saving an additional 32000 Guilders. This is less than what was expected because not every thing could be shifted forward to the periods where it originated from. In this case we try to shift forward in time as far as possible (see the note below) by going through the same cycle another time. The improvement procedure of HS changes the solution structure of table 7 into table 8.

	Product Number															
Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Cap. Req.	SPC
1	8	5	4	0	4	4	6	5	0	8	10	8	10	3	1	334.00	2.00
2	7	4	6	9	6	11	0	2	12	8	0	0	6	3	2	324.20	11.80
3	12	5	6	8	4	0	2	3	0	7	9	8	7	3	3	332.50	3.50
4	5	4	5	8	7	15	7	2	5	8	0	0	8	4	3	332.10	3.90
5	10	5	5	8	6	0	0	3	5	8	9	4	6	3	3	328.50	7.50
6	8	0	4	6	6	0	4	3	12	8	0	4	7	4	3	305.50	30.50
7	12	3	5	7	7	0	3	5	0	8	9	4	6	4	4	334.30	1.70
8	4	12	5	6	5	5	4	0	6	9	0	4	7	4	3	335.90	0.10
9	0	0	6	7	8	0	4	4	6	9	6	9	7	5	5	322.90	13.10
10	6	6	7	7	7	3	4	3	5	9	5	0	6	5	3	334.40	1.60

Table 7 : Solution structure, 1st. round of back shifting procedure

	Product Number															
Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Cap. Req.	SPC
1	8	5	4	0	4	4	6	5	0	8	10	8	10	3	1	334.00	2.00
2	7	4	6	9	6	11	0	2	12	8	0	0	6	3	5	335.30	0.70
3	12	5	6	8	4	0	2	3	0	7	9	8	7	3	0	323.30	12.70
4	5	4	5	8	7	15	7	2	5	8	0	0	8	4	3	332.60	3.40
5	10	5	5	8	6	0	0	3	5	8	9	4	6	3	3	328.50	7.50
6	8	0	4	13	6	0	7	3	12	8	0	4	7	4	3	334.70	1.30
7	12	3	5	0	7	0	0	5	0	8	9	4	6	8	7	331.00	5.00
8	4	12	5	13	5	8	4	0	6	9	0	4	7	0	0	333.40	2.60
9	0	0	6	0	8	0	4	4	11	9	6	9	7	5	5	325.80	10.20
10	6	6	7	7	7	0	4	3	0	9	5	0	6	5	3	302.00	34.00

Table 8 : Solution structure, 2nd. round of back shifting procedure

The total cost of the solution structure presented in table 8 is *fl* 12,208,933, which means an extra savings of *fl* 26,000 is realized. In this structure the following initial shifts can be cancelled.

Product 1 from period 6 to period 10 : 1
Product 1 from period 6 to period 9 : 1

The results are given in the solution structure of table 9. The total relevant cost of this solution is *fl* 12,203,933 which gives additional saving of *fl* 5,000.

Note : Cancelling the initialization shifts should save *fl* 7000 (4000+3000=7000). However, this has not happened because the second shift of the list only in part has been shifted back and the other part (one batch) is moved from period 6 to period 7.

	Product Number																
Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Cap. Req.	SPC
1	8	5	4	0	4	4	6	5	0	8	10	8	10	3	1	334.00	2.00
2	7	4	6	9	6	11	0	2	12	8	0	0	6	3	5	335.30	0.70
3	12	5	6	8	4	0	2	3	0	7	9	8	7	3	0	323.30	12.70
4	5	4	5	8	7	15	7	2	5	8	0	0	8	4	3	332.60	3.40
5	10	5	5	8	6	0	0	3	5	8	9	4	6	3	3	328.50	7.50
6	6	0	4	13	6	0	7	3	12	8	0	4	7	4	3	325.70	10.30
7	13	3	5	0	7	0	0	5	0	8	9	4	6	8	7	335.50	0.50
8	4	12	5	13	5	8	4	0	6	9	0	4	7	0	0	333.40	2.60
9	0	0	6	0	8	0	4	4	11	9	6	9	7	5	5	325.80	10.20
10	7	6	7	7	7	0	4	3	0	9	5	0	6	5	3	302.00	29.50

Table 9 : Solution structure, 3rd. round of back shifting procedure

The production sequence of the last solution structure (table 9) is given in table 10.

Period	Sequence												
1	1	15	14	11	8	12	7	5	13	10	2	3	6
2	6	4	3	8	14	9	10	1	15	13	5	2	
3	2	12	7	5	14	11	8	4	3	13	10	1	
4	1	2	15	13	10	7	5	6	4	3	8	14	9
5	9	10	1	15	14	11	8	4	3	13	5	2	
6	12	7	5	9	4	3	8	14	1	15	10	13	12
7	13	10	1	15	14	11	5	2	3	8	12		
8	12	7	5	6	4	3	13	10	1	2	9		
9	9	10	13	12	7	5	3	8	14	11	15		
10	15	14	11	8	8	3	13	10	1	2	7	5	

Table 10 : Production sequences of last solution structure after back shifting

7. CONCLUSIONS

The increased affordable microcomputer power on factory floors, coupled with central data bases, provides the opportunities to develop simple intelligent procedures for effective lotsizing and sequencing. This paper attempted to further improve the HS-heuristic. Here, solutions obtained are on average 3-6% better than the original heuristic, noting improvement routine worthwhile to be included in the heuristic procedure. The routine is simple and transparent, involving no complicated computation.

Areas for further research may include a combination of existing heuristics developed for similar types of problems. A more educated shifting policy could be developed in the initialization phase which takes care of back-shifting before termination of initialization. This may however, lead to increased computation time. Another dimension of improvement is the sequencing aspect which is solved as a travelling salesman problem. This can be simplified by allowing production of certain products once a major setup takes place (see Carter et al. (1988)).

More research needs to be carried out on the performance measurement of the above heuristic and other similar ones. To measure how well a heuristic finds solutions is a thorny issue, since there is not always an easy way to determine, for a given problem, how good the final solution is. An experimental design which generates several solutions should be conducted. When it is not possible to find the optimal solution, the results should be compared with those generated by an expert with lots of practical experience.

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