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SIMULATION ASSISTED SHOP FLOOR PLANNING

Summary. Simulation has been applied for detailled shop floor scheduling. In the paper the structure of the underlying job shop simulation model and the results of some experiments with it are presented. A case is descibed as is the way of use of the model for scheduling and tracing purposes.

1. Introduction

Generally detailed shop floor planning is not supported by automated production planning systems. For the short term tuning of work load and production capacities detailed information about the needs, of for example, the assembly and the status of parts in production is desirable. This information is often only available a short time in advance, so it could happen that though the overall production capacity is more than sufficient for the work load over a certain period, still due-times are exceeded as a result of bad detail tuning, inadequate lot sizes, peak loads and supposed urgent orders. Improvements appear to be possible using a job shop simulation model.

2. Modelling method

The "process interaction" technique [1],[2] was used for the modelling of the job shop. In the process interaction technique logical classes of components are distinguished. Classes may have both attributes and process descriptions.

Classes in the basic job shop model are: Machine Groups, Machines, Order generator, Orders, Job's and several waiting queues. Only machines and order generators have process descriptions.

Figure 1 shows the job shop and its components schematically. A component has a data structure, which is represented by its attributes. Equal machines are contained in machine groups. Each machine group has its order list.

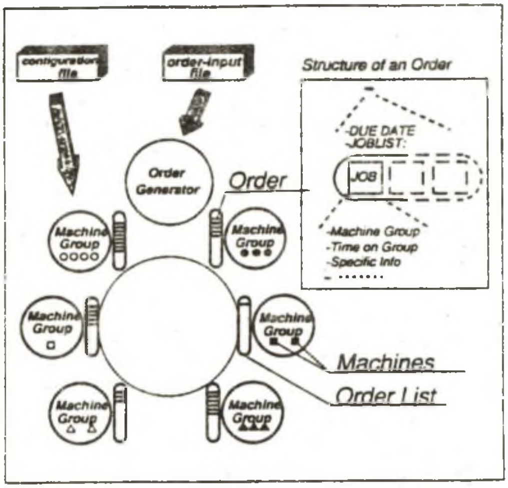


Figure 1. Structure of a job shop simulation model with components: Order generator, Machine groups, Machines, Orders, Jobs en several waiting queues

In this case the data structure of an order is important. Each order has its own Job-list, indicating the sequence of machine groups it has to pass and the processing time for each job. Each order also contains suitable information needed for detailed planning. In general the due-date is needed for that purpose. The generalised order structure is shown in figure 1.

The informal process description of the machine class is given in figure 2. In short each machine takes orders if available, processes them and passes the order to the next machine group. Selecting orders from an order list can be done at different manners. Here the control strategies are implemented. Each machine may have its own set of strategies. Which strategy will be applied in a specific case may depend on the order on hand and the status of other machine groups.
Any job shop configuration can be modelled in this way.

```
WAIT WHILE there are no ORDERS in the ORDER-LIST of MY GROUP
        (MY GROUP is an attribute of a Machine and
           refers to the GROUP this Machine belongs to.
           ORDER-LIST is an attribute of a GROUP.)

   - SELECT an ORDER from the ORDER LIST of MY GROUP
   - WORK during the PROCESSING TIME of the corresponding JOB
     in the JOB_LIST of selected ORDER
   - PUT the ORDER in the ORDER-LIST of the next MACHINE-GROUP
     (this information is obtained from the ORDER via its JOB_LIST)

REPEAT this process
```

Figure 2. Informal description of the process of a machine

The formal model is coded in a simulation language [3], which supports the process interaction method.

3. Model input

In general a job shop model needs configuration data and order flow data. Here two input files are used. An example of a configuration file is given in figure 3.

The order flow is supplied by the order-input file. A record in this order-input file contains all necessary attributes of an order such as: part name, arrival time, due-date, specific information f.i. thickness of plate , diameter and a list of jobs to be done and for each job its processing times.
The order generator will read order data from the order-input file and creates orders with the structure given in figure 1.

```
{Configuration file of  JOB SHOP model  }
{Orderflow: AV. order flow: orders/hour:]   0.10
{Number of machine groups              :}  14

{groupID Group Name  Mach.Name Type #Machines ]

  'R'    'release'    'releaser' 1     1
  'T'    'transport'  'mover'    2     7
  'A'    'lasercut'   'lacutter' 4     1
  'B'    'sawing'     'saw-mach' 4     2
  'C'    'drilling'   'drllmach' 4     1
  'D'    'welding'    'wldunit'  4     4
  'E'    'milling'    'millmach' 4     2
  'F'    'painting'   'paintmch' 4     1
  'G'    'drying'     'dry-Unit' 4     5
  'H'    'assembly'   'assembl.' 5     3
  'I'    'grinding'   'gringmch' 4     3
  'J'    'bending'    'bendmch'  4     1
  'K'    'testdep1'   'test1'    4     1
  'L'    'testdep2'   'test2'    4     3
```

Figure 3. Example of a configuration file for the basic job shop model

In practice configuration- and order-input files must be obtained from the factory's data base, so a link/interface must be made between the simulation model and these factory files. Here only files composed of fictitious data are shown.

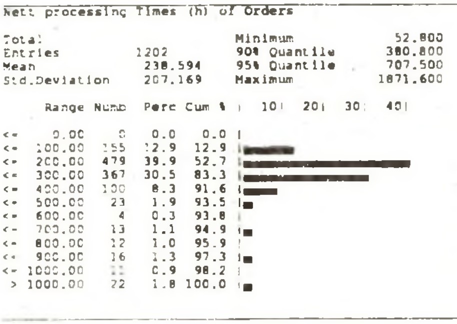
```
{Routes of orders  | Fraction of}
{along Mach.Groups | Occurence   }

'RTATDETFGTHITKL'         0.05
'RTATJTITFGTL'            0.1
'RTATCTETFGK'             0.3
'RTITJ'                   0.2
'RTHTKTL'                 0.2
'RTBTJTITH'               0.05
'RTETATCTL'               0.1
```

Figure 4. Order routes

4. Simulation

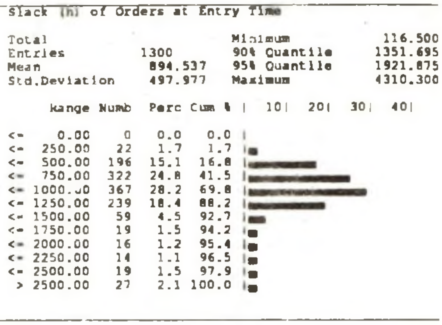
When simulating, a realistic representation of the real processes is obtained. Information produced with the model can be used for evaluation and planning purposes.

Some test runs with the basic job shop model will now be discussed. The configuration of figure 3 is used.



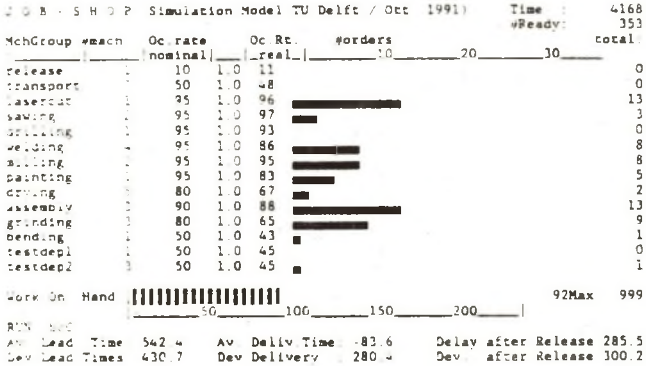
```
Nett processing Times (h) of Orders

Total                          Minimum            52.800
Entries           1202         90% Quantile      380.800
Mean               238.594     95% Quantile      707.500
Std.Deviation      207.169     Maximum          1871.600

      Range  Numb  Perc  Cum %  |   10|   20|   30|   40|

<=     0.00     0   0.0    0.0  |
<=   100.00   155  12.9   12.9  |
<=   200.00   479  39.9   52.7  |
<=   300.00   367  30.5   83.3  |
<=   400.00   100   8.3   91.6  |
<=   500.00    23   1.9   93.5  |
<=   600.00     4   0.3   93.8  |
<=   700.00    13   1.1   94.9  |
<=   800.00    12   1.0   95.9  |
<=   900.00    16   1.3   97.3  |
<=  1000.00    11   0.9   98.2  |
 >  1000.00    22   1.8  100.0  |
```

Figure 5. Distribution of total nett order-processing times



```
Slack (h) of Orders at Entry Time

Total                          Minimum           116.500
Entries           1300         90% Quantile     1351.695
Mean               894.537     95% Quantile     1921.875
Std.Deviation      497.977     Maximum          4310.300

      Range  Numb  Perc  Cum %  |   10|   20|   30|   40|

<=     0.00     0   0.0    0.0  |
<=   250.00    22   1.7    1.7  |
<=   500.00   196  15.1   16.8  |
<=   750.00   322  24.8   41.5  |
<=  1000.00   367  28.2   69.8  |
<=  1250.00   239  18.4   88.2  |
<=  1500.00    59   4.5   92.7  |
<=  1750.00    19   1.5   94.2  |
<=  2000.00    16   1.2   95.4  |
<=  2250.00    14   1.1   96.5  |
<=  2500.00    19   1.5   97.9  |
 >  2500.00    27   2.1  100.0  |
```

Figure 6. Distribution of slack at arrival of orders



```
J O B - S H O P  Simulation Model TU Delft / Oct  1991)     Time   :      4168
                                                            #Ready:       353
MchGroup #mach    Oc rate      Oc Rt.    #orders                        total
________|______|nominal|___|_real_|________10________20________30_____
release      1         10   1.0   11                                       0
transport    -         50   1.0   48                                       0
lasercut     1         95   1.0   96                                      13
sawing       1         95   1.0   97                                       3
drilling     1         95   1.0   93                                       0
welding      4         95   1.0   86                                       8
milling      1         95   1.0   95                                       8
painting     1         95   1.0   83                                       5
drying       [illegible] 80   1.0   67                                       2
assembly     2         90   1.0   88                                      13
grinding     3         80   1.0   65                                       9
bending      1         50   1.0   43                                       1
testdep1     1         50   1.0   45                                       0
testdep2     3         50   1.0   45                                       1

Work On  Hand  |||||||||||||||||||                           92Max    999
               |_______50________100_______150________200_____|
RUN  [illegible]
Av  Lead  Time   542.4    Av  Deliv Time   -83.6    Delay after Release 285.5
Dev Lead Times   430.7    Dev Delivery     280.4    Dev   after Release 300.2
```

Figure 7. Screen image, giving the status of the system during simulation

The order-input file contains some 1200 orders which arrived at an average rate of one per ten hours. The order characteristics are shown in figures 4-6.

Figure 4 shows the seven types of order-routes. Orders with equal routes may have quite different processing times on the subsequent machine groups. Figure 5 gives the distribution of total nett processing times of the orders and figure 6 shows the slack at order arrival. The slack S of an order is defined as:

S = ODT - NOW - TPT, in which ODT is the order due time (or date) NOW is the current time and TPT is the total nett processing time of the order. Consequently the slack is a dynamic parameter.

5. Results

Some simulation results are presented in figures 7-9. Figure 7 gives the screen image which provides, during the simulation run, the status of the system. In figure 8 the results of two runs with different control strategies are shown. a: order selection at machine group level, based on first in first out and b: order selection based on the rule : smallest slack first. In this way the model can be used for evaluation purposes.

In figure 9 the detailed registration with respect to a part of the order flow is presented in two ways. a: Order-oriented, following one order on its way through the factory and b: Machine-oriented, looking at the flow of orders along one specific machine.
These two types of simulation output appears to be very useful for detailed shop floor scheduling purposes.

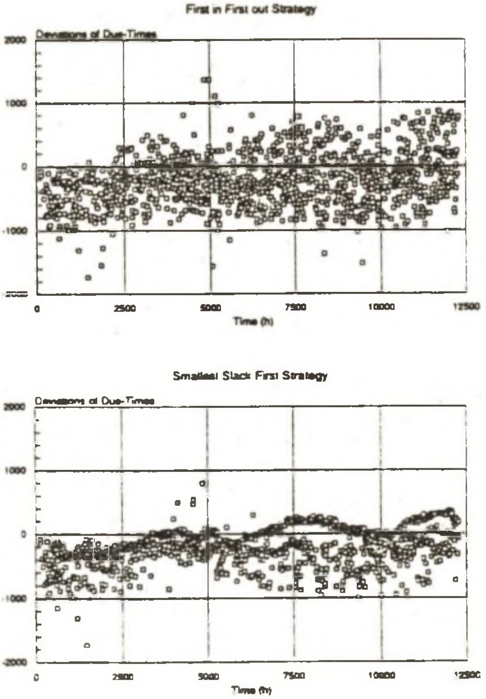


Figure 8. Simulation results: Distribution of deviations from due dates of approximately 1200 orders at two control strategies. The same order-input file is used. Negative means completion too early; positive means too late

6. Case: Use of the job shop model in practice

After some modifications, the basic job shop model was implemented in the factory of MOBA bv, located in Barneveld, the Netherlands [4]. This company produces egg sorting machines for clients throughout the world. The company has about 300 employees. The product program consists of seven types of sorters, the capacities of which varies up to 90.000 eggs per hour. The sorters are very complicated installations and contain many specific parts. The total number of parts in use is about 20.000. Of these 60% are home made in a job shop. The machine file of this job shop contains 145 machine numbers. Many of the machines are numerically controlled.

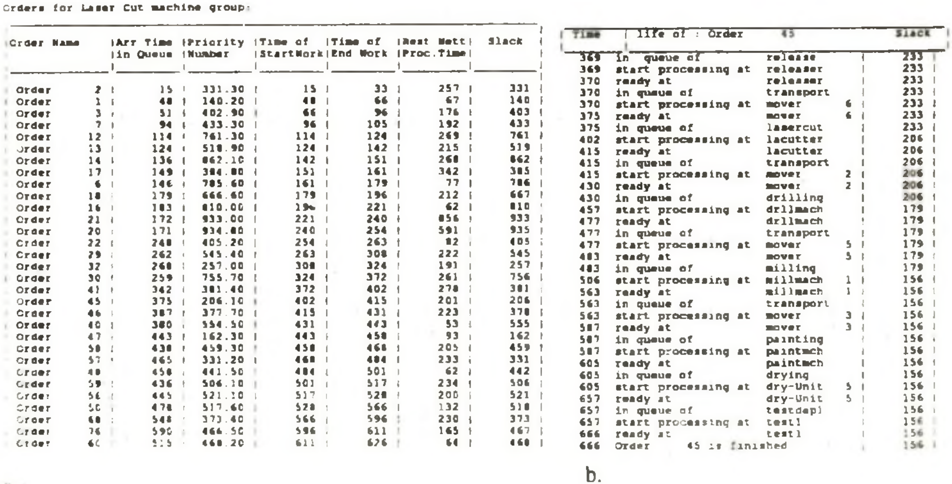
6. 1.Production planning

The assembly activities are fully customer-oriented as is the production of the main components. This is planned with the help of an MRP system. All assembly activities are performed under direct management.

The simulation model concerns the inventory driven supply of parts for the main components. An "out of stock" situation for a certain part is signalled six weeks ahead on the basis of planned main components. At that moment a replenishment order for the part is released with a lot size of approximately one quarter of the estimated annual demand for that part.

During manufacturing several priority rules are used. Mostly planning on slack basis is applied. However this can be overruled, for instance in case of long machine adjusting times. Sometimes the "work in next queue" rule is used.

An order becomes urgent if its slack becomes smaller than one week. In that case a red sticker is fixed onto the order form and the machine operators are supposed to give priority to processing these marked orders. Apart from the laborious activity of searching for urgent orders and fixing stickers on to them, there is no indication of mutual priorities among urgent orders. As a result the delivery of orders in due-time can not be guaranteed.



```
Orders for Laser Cut machine group:

|Order Name    |Arr Time |Priority |Time of  |Time of  |Rest Mett|  Slack  |
|              |in Queue |Number   |StartWork|End Work |Proc.Time|         |
|              |         |         |         |         |         |         |

 Order      2 |      15 |  331.30 |      15 |      33 |     257 |     331 |
 Order      1 |      48 |  140.20 |      48 |      66 |      67 |     140 |
 Order      3 |      51 |  402.90 |      66 |      96 |     176 |     403 |
 Order      7 |      94 |  433.30 |      96 |     105 |     192 |     433 |
 Order     12 |     114 |  761.30 |     114 |     124 |     269 |     761 |
 Order     13 |     124 |  518.90 |     124 |     142 |     215 |     519 |
 Order     14 |     136 |  862.10 |     142 |     151 |     268 |     862 |
 Order     17 |     149 |  384.80 |     151 |     161 |     342 |     385 |
 Order      6 |     146 |  785.60 |     161 |     179 |      77 |     786 |
 Order     18 |     179 |  666.60 |     179 |     196 |     212 |     667 |
 Order     16 |     183 |  810.00 |     196 |     221 |      62 |     810 |
 Order     21 |     172 |  933.00 |     221 |     240 |     856 |     933 |
 Order     20 |     171 |  934.80 |     240 |     254 |     591 |     935 |
 Order     22 |     248 |  405.20 |     254 |     263 |      82 |     405 |
 Order     29 |     262 |  545.40 |     263 |     308 |     222 |     545 |
 Order     32 |     268 |  257.00 |     308 |     324 |     191 |     257 |
 Order     30 |     259 |  755.70 |     324 |     372 |     261 |     756 |
 Order     41 |     342 |  381.40 |     372 |     402 |     278 |     381 |
 Order     45 |     375 |  206.10 |     402 |     415 |     201 |     206 |
 Order     46 |     387 |  377.70 |     415 |     431 |     223 |     378 |
 Order     40 |     380 |  554.50 |     431 |     443 |      53 |     555 |
 Order     47 |     443 |  162.30 |     443 |     458 |      93 |     162 |
 Order     58 |     438 |  459.30 |     458 |     468 |     205 |     459 |
 Order     57 |     465 |  331.20 |     468 |     484 |     233 |     331 |
 Order     48 |     458 |  441.50 |     484 |     501 |      62 |     442 |
 Order     59 |     436 |  506.10 |     501 |     517 |     234 |     506 |
 Order     56 |     445 |  521.10 |     517 |     528 |     200 |     521 |
 Order     50 |     478 |  517.60 |     528 |     566 |     132 |     518 |
 Order     68 |     548 |  373.40 |     566 |     596 |     230 |     373 |
 Order     76 |     590 |  466.50 |     596 |     611 |     165 |     467 |
 Order     60 |     515 |  468.20 |     611 |     626 |      64 |     468 |
```

a.

```
| Time  | life of : Order      45                      Slack |
|       |                                                     |
  369  in  queue of          release          |         233 |
  369  start processing at  releaser          |         233 |
  370  ready at             releaser          |         233 |
  370  in queue of          transport         |         233 |
  370  start processing at  mover        6    |         233 |
  375  ready at             mover        6    |         233 |
  375  in queue of          lasercut          |         233 |
  402  start processing at  lacutter          |         206 |
  415  ready at             lacutter          |         206 |
  415  in queue of          transport         |         206 |
  415  start processing at  mover        2    |         206 |
  430  ready at             mover        2    |         206 |
  430  in queue of          drilling          |         206 |
  457  start processing at  drllmach          |         179 |
  477  ready at             drllmach          |         179 |
  477  in queue of          transport         |         179 |
  477  start processing at  mover        5    |         179 |
  483  ready at             mover        5    |         179 |
  483  in queue of          milling           |         179 |
  506  start processing at  millmach     1    |         156 |
  563  ready at             millmach     1    |         156 |
  563  in queue of          transport         |         156 |
  563  start processing at  mover        3    |         156 |
  587  ready at             mover        3    |         156 |
  587  in queue of          painting          |         156 |
  587  start processing at  paintmch          |         156 |
  605  ready at             paintmch          |         156 |
  605  in queue of          drying            |         156 |
  605  start processing at  dry-Unit     5    |         156 |
  657  ready at             dry-Unit     5    |         156 |
  657  in queue of          testdepl          |         156 |
  657  start processing at  test1             |         156 |
  666  ready at             test1             |         156 |
  666  Order      45 is finished              |         156 |
```

b.

Figure 9. Parts of a: Machine-oriented and b: Order-oriented processing information, obtained from a simulation run. These types of lists are used for planning and tracing purposes. This can be illustrated with the help of Order 45

6. 2.After implementation

After implementation of the simulation model in the planning activities, see figure 10, the working method is as follows;

The planning covers a period of six weeks. At least once a week the model is supplied with fresh input: a configuration file with machines to be used in the next period and the updated order-input file. Moreover information with respect to working schedules and maintenance is supplied.

Once all data concerning a certain period are available, the simulation session may start and the planner can see whether or not all jobs are finished within due time. During the simulation run detailed information about order status, lead times, work on hand, machine occupation, order sequences on machine groups, arrival times of orders on machine groups are registered. This is accomplished with the help of a data base, which interacts with the simulation model. When simulation results are not quite satisfying because some orders are over time, it is possible to adjust the order-input file by manipulating the data base, for instance by changing lot sizes and priorities. When a lot size is adjusted by making it smaller, of course the remaining part of the lot has to be rescheduled. It then has a lower priority.

As soon as a satisfactory schedule has been obtained, the machine- oriented lists (fig. 9a) of order sequences with estimated starting and completion times are printed and passed to the machine operators. The operator can now process his orders in the right sequence and is able to recognise order delays at a very early stage. The cause of the delay can easily be detected by using an order-oriented list (fig. 9b) which gives information about preceding processing steps. Orders, which in spite of the planning, exceed there due-time are rescheduled in the next week and automatically provided with an extra high priority.

At the moment simulation takes a central place in short time scheduling at the factory of MOBA. Beside for scheduling purposes, the simulated lists are also used for providing machines with CNC programs and tools in time.

As a Spin Off of this work, a generic model called Bottleneck Avoiding Resource Planning (BART) is made [5] and applied by several Dutch manufacturers.

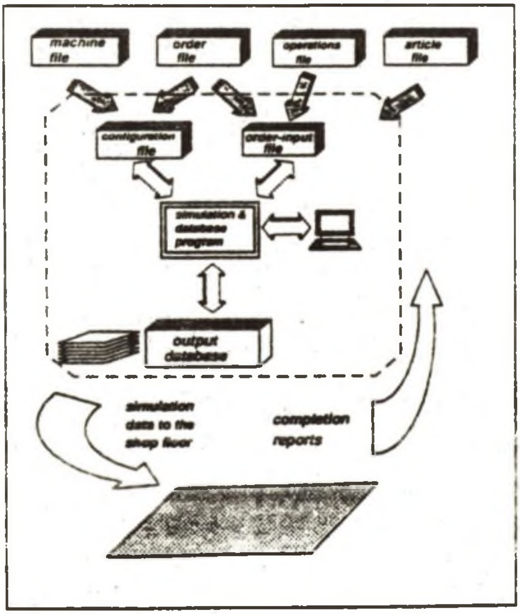


Figure 10. The simulation model integrated in the shop floor planning system

7. Conclusions

Apart from using simulation for the long term evaluation of control strategies and changes in configuration, it may very well be used for detailed short time shop floor planning. By repeatedly running the simulation model and adjusting the job mix, the planner is able to produce a realistic production schedule. Moreover the simulation results can be used for actual scheduling purposes at machine level and for detecting delays and disturbances during production. New orders can be realistically planned and management has an overview of production progress.

A necessary condition is the possession of a detailed simulation model allowing flexible configuration and implementation of production control strategies and rules. The process interaction method appears to be very useful for this purpose.

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SIMULATION UNTERSTUTZTEN SHOP FLOOR PLANNING

Zusammenfassung. Simulation ist angewendet worden für detaillierten Shop Floor scheduling. In der Arbeit wird die Struktur des Job Shop Simulationsmodelles und das Ergebnis einiger Experimenten dargestellt. Ein Beispiel und das Verfahren mit dem Modell wird erklärt.

SYMULACJA WSPOMAGANIA PLANOWANIA PRZYGOTOWANIA PRODUKCJI

Streszczenie

Symulacja została zastosowana dla dokładnego planowania warsztatowego. W artykule zaprezentowano strukturę modelu symulacyjnego oraz rezultaty zaprezentowanego eksperymentu. Opisano przykład zastosowania modelu.

Wpłynęło do redakcji w styczniu 1992r. Recenzent: Jan Kosmol