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Abstract

Work flows in a job-shop are determined not only by the release load and the time between release factors, but also by the number of accepted orders. There has been extensive research on workload and input-output control aiming at improving the performance of manufacturing operations in job-shops.

This paper explores the idea of controlling the workload since the acceptance/rejection of orders stage. A new acceptance/rejection rule is proposed, and tests are conducted to study the sensitivity of job-shop performance to different order acceptance parameters, like the tolerance of the workload limit and the due date extension acceptance. It also evaluates the effect of the negotiation phase of the proposed acceptance rule on the job-shop performance using a simulation model of a generic random job-shop. The extensive simulation experiments allow us to conclude that having a negotiation phase prior to rejection improves almost all workload performance measures. We also conclude that different tolerances of the workload limit affect slightly the performance of the job-shop.

JEL Code: M11 Production Management

Key words: job-shop; acceptance decision; workload control; simulation.

I. INTRODUCTION

In recent years, workload and input-output control have been attracting increased attention among researchers. However, these studies focus mostly on workload control only after the orders have been accepted, i.e., traditionally the workload in a job-shop is controlled at the order release stage. Alternatively, decisions on workload control can be made earlier, at the stage of order acceptance or rejection. It may be seen as a rather extreme form of workload control, but if this decision is made using an appropriate rejection rule of the incoming candidate orders, it may be advantageous for the system as a whole. When capacities are fixed and demand is high the company has to decide which orders to accept and which orders to reject. Rejecting an order may be more favourable to the goodwill of the company than accepting all orders regardless of capacity restrictions and, consequently, completing a significant percentage after their due date.

In this paper the common assumption of accepting all incoming orders regardless of shop condition is relaxed. Instead of placing the orders in a "pre-shop pool" queue as in previous research, orders that arrive at the shop, when it is highly congested, may be immediately rejected or the due date may be negotiated. Actually, when the shop is congested, accepting all orders will endanger the ability of the job-shop to meet due dates.

A new acceptance/rejection rule is proposed, and tests are conducted to study the importance of having a negotiation stage before definitely rejecting the order. The sensitivity of the shop performance to different order acceptance parameters is also analysed. The proposed acceptance/rejection rule, called DDN (Due Date Negotiation), takes into account three types of information: (i) the total workload of jobs in-process plus jobs waiting in the pre-shop pool; (ii) a pre-defined tolerance of the workload limit (called negotiation margin); and (iii) the order's due date. The idea behind this new rule is to allow for the acceptance of new orders when the workload limit is exceeded by only a small percentage. With this rule, the number of rejected orders decreases and the shop-floor congestion is controlled through the due date negotiation.

The operational performance measures used to evaluate the acceptance rule are the percentage of tardy jobs and the mean tardiness — related to delivery performance— and the mean queue time in the shop-floor, the mean earliness (mean wait time in final products inventory) and the shop-floor (machine) capacity utilization — related to workload performance. Since performance measures are influenced not only by the parameters of the acceptance rule but also by other decisions made in the shop-floor (namely, the release and the dispatching decision), a benchmark rule and a *good* rule previously presented in the literature are considered for each of these decisions.

The simulation experiments were performed to investigate whether the negotiation phase improves the job-shop workload control by comparing selected performance measures in the two situations (with and without negotiation). The results allow us to conclude that having a negotiation phase prior to rejection improves almost all workload and delivery related performance measures. The simulation results also show that the shop performance is sensitive to the customer acceptance probability of the new delivery date and that different tolerances of the workload limit do affect the performance of the job-shop.

This paper has three main objectives: firstly, to present, simulate and test a new decision rule (to accept or not an incoming order), secondly, to investigate whether the order negotiation phase improves the shop-floor performance, and thirdly, to study the sensitivity of the shop performance to different order acceptance parameters, like the tolerance of the workload limit and the due date extension acceptance.

The remainder of this paper is structured as follows. In the following section a brief literature review on order acceptance is presented. Then, the proposed acceptance/rejection rule is introduced, together with a description of the simulation manufacturing environment in which it is tested. The research methodology (simulation model, experimental factors, performance measures and data collection) is outlined afterwards. Following this, the results of the simulation experiments are presented and discussed, and in the final section some conclusions and possible directions for future research are highlighted.

II. BRIEF LITERATURE REVIEW

Despite a clear early concern about workload control (Wight, 1970), order acceptance has received limited attention in the literature. Most papers have focused on alternative methods for releasing jobs to the shop-floor. A good survey and classification of the research in the field of order review and release (ORR) can be found in Bergamaschi et al. (1997).

In the literature, order acceptance decisions are often based on the workload content of the order, related to the available workload. On the experimental side, Philipoom and Fry (1992), ten Kate (1994) and Wester et al. (1992) compare different order acceptance strategies (algorithms) using simulation. Wang et al. (1994) proposed a neural network approach for multiple criteria order acceptance decisions, such as profit and customer credit. Wouters

(1997) presents an economic evaluation of the order acceptance decision suggesting ways to further improve the usefulness of the relevant cost approach to that decision.

More recently Raaymakers et al. (2000a, 2000b) study the performance of workload control rules for order acceptance in batch chemical manufacturing. The research of Ivanescu et al. (2002) was built on those works by investigating order acceptance when processing times are uncertain. Enns (2000) and Enns and Costa (2002) evaluate the input control at the shop-floor based on aggregate workload measures. Using simulation, Nandi and Rogers (2003, 2004) present a make-to-order manufacturing system under a control policy involving an order acceptance/rejection component. Moreira (2005) studies the job-shop as a multiple decision making problem, where the acceptance/rejection decision is taken into consideration.

Two more papers must be included in this brief literature review: the work of Calosso et al. (2003) and of Ebben et al. (2005). Calosso et al. (2003) discuss in detail the structure for a standardised negotiation process in electronic commerce. Ebben et al. (2005) use a simulation model of a generic job-shop to compare the sophisticated proposed approaches with straightforward methods.

In the light of the above discussion, it should be interesting to investigate the behaviour of a system with and without orders input control.

III. THE ORDER ACCEPTANCE/REJECTION RULE

In this section the acceptance/rejection decision is placed in the global decision making process. After this, the proposed acceptance rule is described in detail. The production control system, for the kind of job-shop considered, consists of four stages: 1) acceptance, negotiation or rejection of an order, 2) due date assignment, 3) order release, and 4) order dispatch.

The accept/negotiate/reject decision is made when a costumer places an order. In this paper two rules are considered: total acceptance (TA), used as a benchmark, and the proposed rule, the due date negotiation (DDN). The decision about the due date assignment is made simultaneously with the acceptance decision, and a negotiation with the costumer may occur. We will consider only one due date assignment rule because, by varying the planning parameter, it is possible to convert one rule into another. The total work content (TWK) rule defines the due date by adding a certain amount, representative of the time that the job will need to be completed, to the order's arrival date:

$$DD_i = AD_i + k_{TWK} \times P_i \ , \qquad (1)$$

where: DD_i: due date of job i;

AD_i: job i arrival date;

P_i: processing time of job i;

k_{TWK}: planning factor.

After an order has been accepted, it is placed in a pre-shop pool file. The order release rule defines when a release must take place and which of the orders will be released to the shop-floor. Two order release rules are considered: immediate release (IMR) and modified infinite loading (MIL). The IMR release rule is used as a benchmark: as soon as an order is accepted it is released to the shop-floor. The MIL rule was proposed by Ragatz and Mabert (1988) as an extension of the backward infinite loading rule (BIL), which consists in deducting from the due date the expected job flow time. It is similar to the BIL rule (because it ignores the shop capacity), but it has more information to predict the job flow time since it includes a factor about the present work on the shop. MIL determines the job release date as follows:

$$RD_i = DD_i - k_{1MIL} \times n_i - k_{2MIL} \times Q_i \ , \qquad (2)$$

where: RD_i: release date of job i;

DD_i: due date of job i;

n_i: number of operations of job i;

Q_i: number of jobs in queue on job i routing;

k_{1MIL}, k_{2MIL}: planning factors.

Once a job is released to the shop-floor, its progress is controlled by the selected dispatching rule. We will consider the first-come-first-serve rule (as a benchmark) and the earliest due date (EDD) rule. When all processing has been completed, the order is placed in a finished-goods inventory until its delivery (due) date. Figure 1 shows these four decisions and the relationships among them, using the Arena software layout, the software package applied to the simulation experiments.

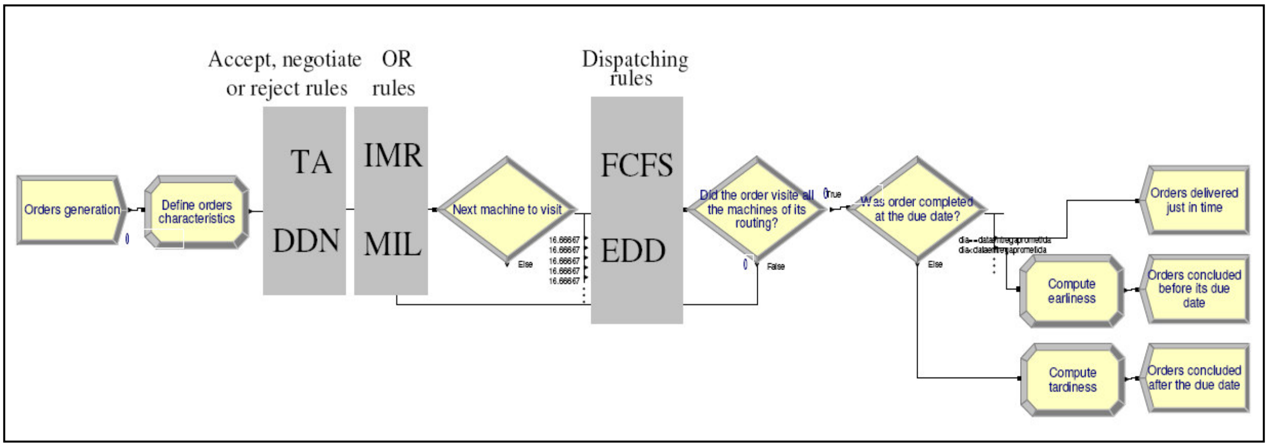

Figure 1 – Multiple decision-making scheme in software Arena

The proposed due date negotiation (DDN) rule works as follows: when an order arrives, the total workload in the shop (considering the jobs on the shop-floor and the jobs waiting for release) is computed. If it is lower than a pre-defined limit, the order is immediately accepted. However, if the total workload exceeds that limit, one of two decisions may be made: the negotiation of the due date or the rejection of the order. Due date negotiation exists whenever the pre-defined limit is exceeded by only a certain (small) percentage (the negotiation margin). In this case, an extension of the order’s delivery date is proposed to the customer; if the customer accepts the new delivery date (which happens with a certain probability), the order is accepted. If there is no negotiation or if the customer does not accept the new delivery date the order is rejected. In Figure 2 we can see how the DDN rule works. The design is presented using the Arena software layout.

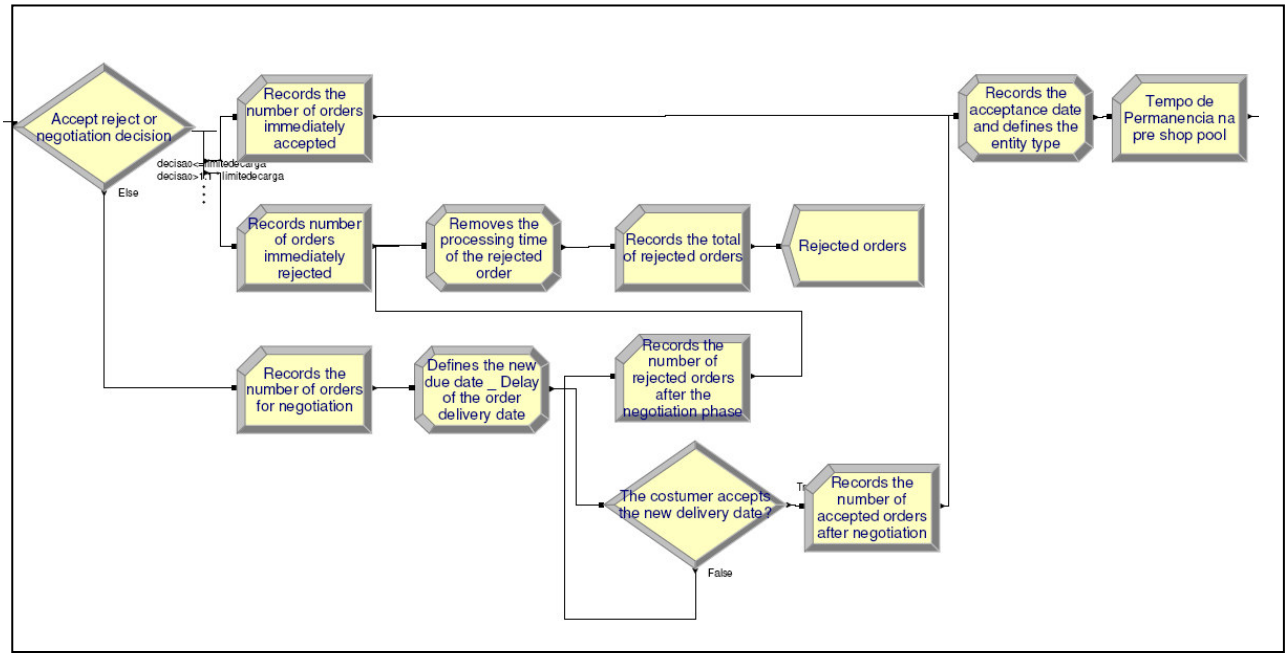

Figure 2 – Due date negotiation (DDN) rule in software Arena

The general code (algorithm) behind the proposed acceptance rule is as follows:

If *Total workload on the shop-floor <= Workload limit,* ***Then*** *Order is immediately accepted*

  Next *(Count, Orders immediately accepted)*

  Next *(Assign, Acceptation date and Entity type)*

Else If *Total workload on the shop-floor>= Workload limit + Negotiation margin,* ***Then*** *Order is immediately rejected*

  Next *(Count, Orders immediately rejected)*

  Next *(Dispose, Rejected)*

Else *Order goes for negotiation*

  Next *(Count, Orders for negotiation)*

  Next *(Assign, New delivery date)*

  Next *(****If*** *Customer accepts the new delivery date,* ***Then*** *Order is accepted*

    Next *(Count, Accepted orders after negotiation)*

    Next *(Assign, Acceptation date and Entity type)*

   Else *Order is rejected,*

    Next *(Count, Rejected orders after negotiation)*

    Next *(Dispose, Rejected)*

   End If*)*

End If

The DDN rule has several parameters that must be carefully defined. We will test the sensitivity of the shop performance to some of them (tolerance of the workload limit — negotiation margin — and the due date extension acceptance). The others will be maintained fixed. Table 1 summarizes the parameters that need to be specified.

Table 1 – DDN parameters

Parameter	Description
L_{Max}	Workload limit to accept an order
Ddd	Delay (in percentage) of the original delivery (due) date
Nm	Negotiation margin
Pa	Percentage of costumers that accepts the new delivery date

The workload limit to accept an order (L_{Max}) depends on the order's delivery date and on the number of machines the order has to visit in its routing. Equation (3) shows how it is computed.

$$L_{Max} = \frac{89*(\text{due date} - \text{present date})}{\text{Number of machines that are in the order's routing}} \qquad (3)$$

On the one hand, the greater the difference between the due and the present date the greater the chance to deliver the order in time. On the other hand, the greater the number of machines the order has to visit the more the shop-floor will be work-loaded. If the machines have a high utilization, orders that have a less complex routing will have priority. L_{Max} is defined so that the mean percentage of rejected orders is 5%, when the DDN, the IMR and the FCFS rules are in use. The delay of the original delivery (due) date is defined as a percentage of the original due date, not in days, and is equal to 5%. This percentage should not be very high to be a good representation of what happens in the real manufacturing system.

The negotiation margin is the amount (in percentage) that the workload limit may be exceeded without an order being rejected. As we want to control the workload, this percentage should be very small. As a benchmark to compare the situation with and without negotiation, we will set *Nm* = 10%. Later on, we will test the sensitivity of job-shop performance to different tolerances of the workload limit. The parameter *Pa* corresponds to the percentage of costumers that accept the extension of the original due date. *Pa* is set at 70%, and the sensitivity of job-shop performance to different values of *Pa* is also tested.

IV. RESEARCH METHODOLOGY

Shop-floor characteristics

Orders are assumed to arrive according to a Poisson process. Besides the widespread use of the Poisson distribution, there is some theoretical evidence that it provides a good approximation for the arrival process (Albin, 1982). The routing for each order and the processing time at each station is generated at this stage. The routing is purely random: the number of operations follows a discrete uniform probability distribution between one and six machines. The order has an equal probability of having its first operation in any of the six machines and of going to the other machines, until being completed. After the definition of the job characteristics, the order is placed in a pending (for acceptance) orders file.

Simulation model

The simulation model was developed using the software Arena 7.1 (Kelton et al., 2004). The characteristics of the hypothetical job-shop are identical to those used by Melnyk and Ragatz (1989): the shop consists of six work centres, operating 40 hours per week; each work centre contains a single machine that can process only one job at a time, and no preemptions are allowed; job routings are random, with no return visits, and the number of operations per order is uniformly distributed between one and six. Order arrivals follow a Poisson process with a mean of 1 order per hour. The processing time distribution for all six machines is identical: exponential with a mean of 1.5 hours. These characteristics result in a steady state utilization rate of 87.5% for each work centre and for the shop as a whole.

Experimental factors

In testing the acceptance/rejection rule, it is important to assess whether the performance is affected by other factors in the planning system, such as the order release and the dispatching rules being used. Therefore, we use a full $2 \times 2 \times 2$ experimental design: the two accept/reject rules described above are simulated in combination with the two order release rules and the two priority dispatching rules presented. The value of the planning factor (k_{TWK}) in the due date formula described above is set at 38, because, with this value, the percentage of tardy jobs is about 10%, when the DDN, IMR, and FCFS rules are simulated.

In testing the sensitivity of job-shop performance to different order acceptance parameters, we use a full $1 \times 2 \times 2 \times 8$ experimental design: the DDN accept/reject rule is simulated in combination with two order release rules, two priority dispatching rules and eight levels for the negotiation margin *Nm* (20%, 15%, 12.5%, 10%, 7.5%, 5%, 2.5% and 0%). *Nm* = 0% corresponds to the situation where negotiation does not occur, but the rejection can take place if the workload limit is surpassed. In the other extreme case, the workload limit can be exceeded by 20% without having a rejection.

The sensitivity of job-shop performance to the percentage of costumers that accept the new delivery date is also tested. Here, we use a 24 experimental design: the DDN accept/reject rule is simulated in combination with two order release rules, the two priority dispatching rules and six levels for the due date extension acceptance (the percentage of costumers that accept the new delivery date varies between 50% and 100%). When *Pa* is 100%, all costumers accept the due date extension. Similarly, when *Pa*=50% only half the costumers accept the new delivery date.

Performance measures

In order to assess the impact of the decision rules on manufacturing performance, specific performance criteria must be selected. Five measures of job-shop performance are considered.

These measures are broken down in two categories:

(i) Due date related performance measures, which are indicative of costumer satisfaction and deliverability: mean tardiness and percent tardy.

(ii) Workload related performance measures, which are used to evaluate the impact of the load observed on the shop-floor: mean wait time in final products inventory, mean queue time in the shop-floor and machine utilization.

Data collection

During simulation runs data are collected with reference to the steady state of the system. In order to remove the effects of the warm-up period, several runs of the simulation model were made to see when the steady state was reached. Performance criteria and utilization levels reached steady state after approximately 4,000 (simulated) working hours. However, all statistics were set to zero and restarted after a warm-up period of 10,000 simulated hours. Statistics were, then, collected for 90,000 hours. Ten replications were performed for each set of experimental conditions.

V. MAIN RESULTS

In this section, we present the main results of the experiments. The analysis is divided in three parts: the first one discusses if the negotiation phase improves the workload control; the second one presents the main results of the sensitivity analysis to the *Nm* parameter (tolerance of the workload limit or negotiation margin); in the third one the results of the sensitivity analysis to the *Pa* parameter (due date extension acceptance) are presented.

Order negotiation phase

To find out if order negotiation improves the shop-floor workload control we compare the results on the selected performance measures of the TA rule (inexistence of order rejection) with the DDN one. Figure 3 shows the due date and delivery related performance measures. The simulation was made for the eight possible combinations to assess if the differences observed are due to the existence of the order negotiation or are attributable to other factors. For each rule (TA and DDN) we compare the results obtained for the mean tardiness and percentage of tardy jobs in each experimental design. We can observe that the DDN rule results in a better delivery performance in all of the possible combination of decision rules. Actually we can see that the mean tardiness is lower when the option for negotiation is present. Moreover, the percentage of orders delivered after their due date is lower if the DDN rule is used.

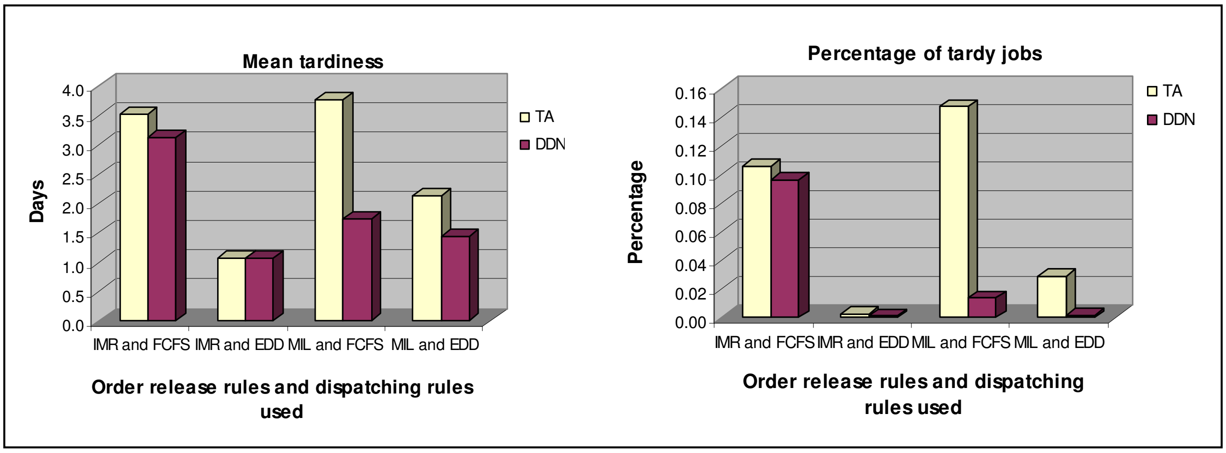

Figure 3 – Due date related performance measures

When we look at the performance measures related with the workload (Figure 4), we notice that the order negotiation, in three of the combinations, allows the order to spend less time in queues inside the shop-floor. And when the order is released as soon as it enters the job-shop and the dispatching rule is EDD, the mean queue time in the shop-floor is almost the same. The only workload measure that has worst results when the DDN is used is the mean wait time in final products inventory (the mean earliness). But, as we can see in the second graphic of Figure 4, the difference is almost unnoticed. Another advantage of the order negotiation is that it implies a slight decrease in the percentage of machine utilization (see third graphic of Figure 4). It is known that one of the constraints job-shops have is the lack of capacity, due to the unstable routings and demand of their products. A decrease in the utilization is good for the shop-floor, because it becomes easier to control the workload.

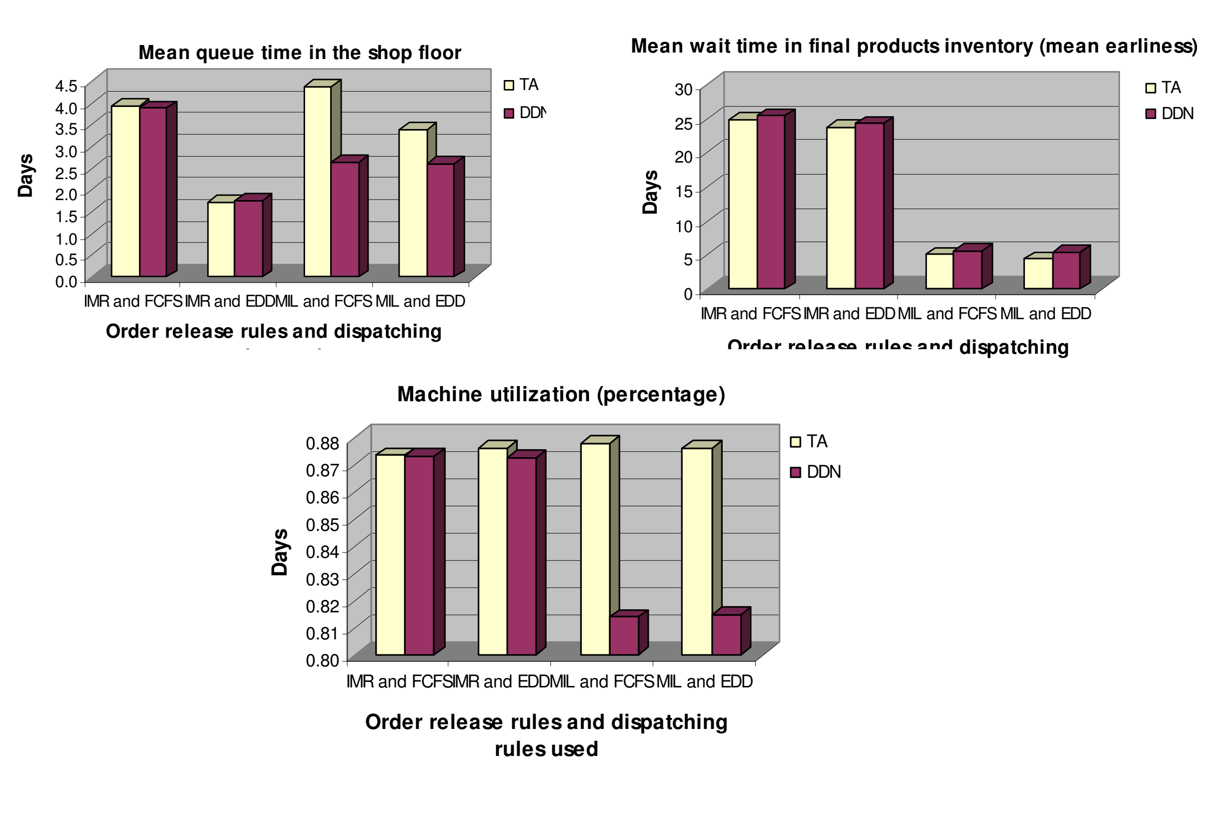

Figure 4 – Workload related performance measures

Sensitivity analysis to Nm parameter

To analyse the sensitivity of the selected performance measures to different values of the negotiation margin, all the other parameters are kept fixed. As mentioned earlier, *Nm* varies from 20% to 0%. Tables 2-5 show the results obtained for the delivery-related and workload related measures of performance. Each of the tables corresponds to a different combination of decision rules, to test if the variations are due to the use of different rules. It can be seen that the only performance measure that is sensitive is the mean tardiness when the combination DDN, MIL and FCFS is used. We also see a slight sensitivity in mean wait time in final products inventory in the design DDN-IMR-EDD.

Tables 2 to 5 – Sensitivity of performance measures to the Nm parameter in the different combinations

NEDE-IMR-FCFS Nm =	20%	15%	12.5%	10%	7.5%	5%	2.5%	0%
Mean tardiness	3.03	3.07	3.14	3.12	3.07	3.03	3.14	3.02
Percentage of tardy jobs	0.09	0.10	0.10	0.10	0.10	0.09	0.10	0.09
Mean queue time in the shop floor	3.84	3.89	3.91	3.88	3.87	3.81	3.95	3.78
Mean wait time in final products invento	25.71	25.60	25.44	25.37	25.23	25.09	25.02	24.79
Machine utilization (percentage)	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87

NEDE-MIL-FCFS Nm =	20%	15%	12.5%	10%	7.5%	5%	2.5%	0%
Mean tardiness	1.68	1.84	1.55	1.75	1.65	1.67	1.78	1.72
Percentage of tardy jobs	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Mean queue time in the shop floor	2.67	2.68	2.64	2.65	2.68	2.65	2.65	2.63
Mean wait time in final products invento	5.59	5.60	5.60	5.62	5.59	5.62	5.63	5.63
Machine utilization (percentage)	0.82	0.82	0.82	0.81	0.82	0.81	0.81	0.81

NEDE-IMR-EDD Nm =	20%	15%	12.5%	10%	7.5%	5%	2.5%	0%
Mean tardiness	1.06	1.06	1.06	1.06	1.05	1.06	1.07	1.05
Percentage of tardy jobs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean queue time in the shop floor	1.83	1.79	1.78	1.77	1.77	1.73	1.73	1.72
Mean wait time in final products invento	24.66	24.46	24.35	24.29	24.16	24.04	23.92	23.76
Machine utilization (percentage)	0.88	0.87	0.87	0.87	0.87	0.87	0.87	0.87

NEDE-MIL-EDD Nm =	20%	15%	12.5%	10%	7.5%	5%	2.5%	0%
Mean tardiness	1.62	1.47	1.56	1.75	1.52	1.41	1.51	1.56
Percentage of tardy jobs	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Mean queue time in the shop floor	2.63	2.62	2.61	2.65	2.59	2.59	2.58	2.57
Mean wait time in final products invento	5.47	5.48	5.48	5.62	5.50	5.50	5.50	5.52
Machine utilization (percentage)	0.82	0.81	0.81	0.81	0.81	0.81	0.81	0.81

Sensitivity analysis to Pa parameter

Tables 6-9 show the results obtained for the delivery-related and the workload-related measures when we vary the percentage of costumers that accept the new delivery date from 50% to 100%. Each of the tables corresponds to a different combination of decision rules, to test if the variations are due to the use of different rules. We can see that there are small variations on the performance measures.

Tables 6 to 9 – Sensitivity of performance measures to the Pa parameter in the different combinations

NEDE-IMR-FCFS Pa =	50%	60%	70%	80%	90%	100%
Mean tardiness	3.12	3.07	3.12	3.03	2.99	3.16
Percentage of tardy jobs	0.10	0.10	0.10	0.10	0.09	0.10
Mean queue time in the shop floor	3.91	3.87	3.88	3.85	3.80	3.96
Mean wait time in final products inventor	25.18	25.31	25.37	25.41	25.50	25.64
Machine utilization (percentage)	0.87	0.88	0.87	0.87	0.87	0.88

NEDE-MIL-FCFS Pa =	50%	60%	70%	80%	90%	100%
Mean tardiness	1.73	1.67	1.75	1.86	1.66	1.79
Percentage of tardy jobs	0.01	0.01	0.01	0.01	0.01	0.01
Mean queue time in the shop floor	2.69	2.69	2.65	2.73	2.71	2.73
Mean wait time in final products inventor	5.59	5.59	5.62	5.57	5.57	5.57
Machine utilization (percentage)	0.82	0.82	0.81	0.82	0.82	0.82

NEDE-IMR-EDD Pa =	50%	60%	70%	80%	90%	100%
Mean tardiness	1.05	1.06	1.06	1.06	1.05	1.05
Percentage of tardy jobs	0.00	0.00	0.00	0.00	0.00	0.00
Mean queue time in the shop floor	1.76	1.78	1.77	1.76	1.80	1.80
Mean wait time in final products inventor	24.16	24.24	24.29	24.36	24.45	24.47
Machine utilization (percentage)	0.87	0.87	0.87	0.87	0.88	0.87

NEDE-MIL-EDD Pa =	50%	60%	70%	80%	90%	100%
Mean tardiness	1.51	1.66	1.45	1.47	1.57	1.59
Percentage of tardy jobs	0.00	0.00	0.00	0.00	0.00	0.00
Mean queue time in the shop floor	2.61	2.62	2.61	2.62	2.58	2.59
Mean wait time in final products inventor	5.47	5.49	5.47	5.47	5.51	5.50
Machine utilization (percentage)	0.81	0.81	0.81	0.82	0.81	0.81

Order negotiation allows for a significant improvement in workload and delivery performance measures, but performance is not very sensitive to the variation of the parameters, namely the negotiation margin (*Nm*) and the due date extension acceptance (*Pa*).

VI. CONCLUSIONS

This paper explores the idea of controlling the workload since the stage of accepting or rejecting incoming orders. A new acceptance/rejection rule, DDN or due date negotiation, is proposed.

It evaluates the impact of different tolerances of the workload limit (*Nm*, the negotiation margin) on the shop performance using a simulation model of a generic random job-shop and a full factorial experimental design. It also tests the influence of various probabilities of acceptance (*Pa*) by the customers of the new delivery date on the shop performance.

In testing the acceptance/rejection rule and its parameters it is important to assess whether the shop performance is affected by other factors in the planning system, such as the order release and the dispatching rule being used. Therefore, a full experimental design is used: the acceptance/rejection rule described above is simulated in combination with two order release rules (the *immediate release* — a benchmark rule — and the *modified infinite loading* (MIL) rule) and two priority dispatching rules (the *first come first served* (FCFS) — a benchmark rule — and the *earliest due date* (EDD) rule).

The extensive simulation experiments allow us to conclude that both the workload and the delivery performance measures improve with the use of a rule that includes a negotiation phase. We also see that different tolerances of the workload limit affect, to some extent, the performance of the job-shop. The simulation results also show that the shop performance is not very sensitive to the customer acceptance probability of the new delivery date.

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