A Study on Human Performance in Graphic-Aided Scheduling Tasks

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Abstract

In many industrial situations the human acts as the primary scheduler since there often exist various constraints and considerations that may not be mathematically or quantitatively defined. For proper design of interactive scheduling systems, how human strategy and performance are affected by the fashion of human-computer interaction at various levels of task complexity should be investigated.

In this study, two scheduling experiments were conducted. The first one showed that human schedulers could perform better than simple heuristic rules with each of typical performance measures such as average machine utilization, average tardiness, and maximum tardiness. In experiment 2, the effect of providing computer-generated initial solution was investigated. The results was that in complex problems the subjects performed significantly better when the initial solutions were generated by themselves, evidencing the importance of the continuity of strategic search through the problem

Introduction

Job shop scheduling problems have received considerable attention over past decades. Its combinatorial nature poses the principal difficulty involved in solving problems of practical sizes. Generally three problem solving approaches have been utilized: analytic, knowledge-based and interactive approach.

The drawbacks of analytic and knowledge-based approach have led many researchers to conclude that advanced manufacturing systems need an active, "engaged" human operators [7, 10]. In interactive human-computer approach, the human and the computer cooperate to make use of the advantages of each other. Several applicational studies support the merit of using an interactive approach to scheduling [2, 3, 5, 10].

This study primarily concerned with the performance of the human scheduler who uses graphical interface. Two experiments were performed to investigate two questions. First, in a previous research [10] on human performance in FMS scheduling, humans showed inferior performance to some simple dispatching rules on machine utilization. In this study, it was hypothesized that the observed human suboptimality in maximizing machine utilization was not due to the inherent weakness of the human, but was caused by lack of intuitive feedback on the particular measure that hampered developing of proper scheduling strategy.

The second question was if human performance can be benefitted from initial solutions that are calculated and provided by the computer. To study this, human subjects were observed solving problems of two levels of complexity with and without provided initial solutions. For the experiments, a job-shop scheduling simulator was developed, which is explained in the next chapter.

THE EXPERIMENTAL SIMULATOR

The simulator represents a deterministic job shop scheduling environment. It has a computerized Gantt chart which enables direct manipulation using a mouse. It also provides some information aiding features. The simulator was developed using MetaCard™ software which is much similar to HyperCard™ running on Macintosh computers, and can be run in UNIX™ environments.

Our graphical interactive job shop scheduler is composed of four modules: a problem setup module, a scheduling module, a performance recording module, and a help module. Using the problem setup module, the controlled features of the problems including the number of jobs, machines, and job types can be determined. The generated problems also are characterized by required machine routing for each job type, due dates, and processing time of each operation.

The scheduling module is the main part of the simulator in which users schedule given problems by direct manipulation. The actions of human schedulers are recorded by the performance recording module so that the entire scheduling processes can be replayed. In help module, users can get relevant information on the functions of buttons and fields by simply positioning the mouse pointer to the objects.

At the beginning of scheduling, jobs to be scheduled are displayed in the upper part of the screen. Operations included in a job are coded in the same color. The lengths of Gantt chart blocks representing operations are proportional to their processing time. Subjects can move blocks using mouse to the Gantt chart area. Users are aided by the simulator which prohibits illegal machine assignments, removes within-job overlapping automatically, and removes between-job overlapping when asked by pressing the 'Rearrange' button. If the "Rearrange" button is pressed while 'Forward' option is turned on, operation blocks are shifted leftward as far as possible. This guarantees *semi-active* schedules [1, p181].

The performance measures and the total score are displayed when the 'Calculate' button is pressed. Pressing this button, the user indicates that a planned rearrangement is fulfilled. The lateness of each job is always displayed with the most tardy job being highlighted. The overall performance score is defined as a weighted sum of three factors expressed in the next formula.

$$\alpha \Sigma T_i + \beta T_{max} + \gamma C_{max}$$

where

T_i is the tardiness of job i,

T_{max} is the maximum tardiness,

C_{max} is the maximum completion time (makespan),

α, β, and γ are the weights whose sum is 1.

The lower the value of this score, the better the quality of a schedule.

The chart also shows the due dates and marks with red bar the operation blocks that do not fit in their due dates. With these aiding features the scheduler can grasp the overall state of current schedule holistically with little effort.

Besides the above explained, there are numerous other features to help the user undertake the tasks conveniently, and hence, to ensure a merely bad interface design not to affect the performance randomly.

THE EXPERIMENT I

1. Purpose

The purpose of experiment 1 was to observe the development of human scheduling strategies depending on different performance measures. The human may inherently have more difficulty in optimizing a measure than others. Subjects were divided into 3 groups that are assigned three different set of weights for the typical measures: Average machine utilization (Uavg), average tardiness (Tavg), and maximum tardiness (Tmax). The performance of the subjects in each group is also to be compared with that of the selected seven dispatching heuristics. We adopted the 7 rules in Tabe and Salvendy's study [10] to enable comparison, They are simple rules of FCFS and S/OPN and combination rules such as SPT_S, MWKR_F, MWKR_S, MOPNR_S, and EDD_M [10].

2. The Design of Experiment

12 male students participated in the experiment. All the problems have 8 jobs, 8 machines, and slack ratio (due date of the job / total processing time of a job) of 1.5.

Different measures were emphasized in calculating the overall score for the three groups (4 subjects each) respectively. Group 1 was forced to concentrate on minimizing Tavg (α=0.8, β=0.1, γ=0.1), group 2 on minimizing Tmax (α=0.1, β=0.8, γ=0.1), and group 3 on maximizing Uavg (α=0.1, β=0.1, γ=0.8).

The experiment was conducted in two training sessions and a final session.

3. The Results

Analysis of variance on main session of the experiment was performed. As was expected, we observed that group 3 showed better performance on Uavg and group 1 and 2 showed better performance on Tavg and Tmax than the other groups respectively.

The average performance of the 3 groups through 3 sessions are plotted in figure 1 (a)-(c). In the two training sessions, the performance patterns of group 1 and the others gradually differed as the sessions repeat. From this result we can conjecture that subjects in the groups, notably group 3, developed corresponding scheduling strategies. In the figure, the best values of seven selected dispatching rules are also presented as reference points. All the three groups outperformed any of the heuristics with regard to the emphasized measures. Although human scheduling seemed more obviously favorable with minimizing tardiness than

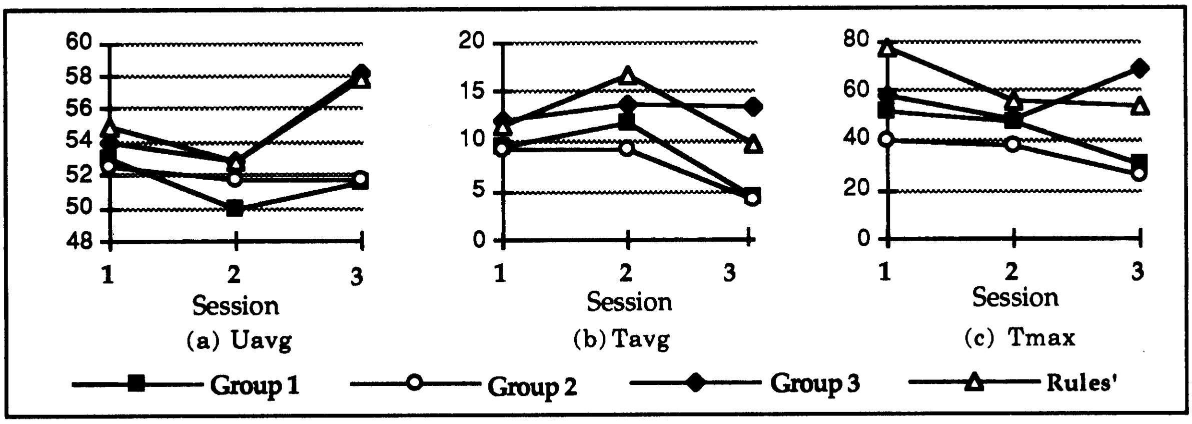

Figure 1. Performance Change through 3 Sessions

maximizing utilization, it is noteworthy that focused training enabled effective strategy for the latter too. Also, the fact that group 3 was forced to sacrifice the tardiness measures implies that, at least in human strategies, tardiness and utilization are somewhat conflicting goals. This explains the human suboptimality in utilization that was found in previous research [10]. That is, the subjects may have delivered schedules with low utilization not because they were inherently bad at the measure, but because they concentrated more upon the tardiness measures and sacrifice utilization as the cost during the process. It is evidenced by that, as utilization is isolated and emphasized for group 3 in this study, the human showed good enough ability as compared to the best of the simple rules.

The Experiment II

1. Purpose

The purpose of the second experiment was to investigate how human performance in job shop scheduling is affected by initial solutions provided by the computer. Since the solution found by the computer can easily be better than the initial solution by the human, the human may be benefitted by utilizing the computer solution as the starting point. This is perhaps the mode of interactive optimization of which possibility should first be examined.

To study this effect, two problem solving modes, manual and semi-manual, and two levels of problem complexity were set. In the semi-manual mode, the initial solution is provided based on the best result obtained by 7 heuristic rules so that the human starts from the solution. The same 7 rules adopted in experiment I were used in semi-manual mode. In the manual mode, the task was the same except that the human must generate the initial solution on his own.

2 Design of Experiment

This experiment adopted within-subject design, in which each subjects solved problems with and without initial solutions that the computer provided. For the purpose of comparison, we distinguished two phases of problem solving in the manual mode. In the mode, users first move the operation blocks displayed in the upper part of screen into the

Gantt chart area manually. We identify this process as phase 1. The result of the phase 1 is the initial solution. Users then try to improve the initial solution by swapping the operation blocks, which is called phase 2. The result of the phase 2 is the final solution.

In the semi-manual mode, phase 1 is performed by the computer and the subjects start from phase 2 only to modify the given solution to construct the final schedule. The computer applies all the seven heuristics and selects the best one for the initial solution.

Eight male students who have little knowledge about algorithmic techniques of scheduling participated. The subjects solved 4 problems with the same order and other 8 problems with the different order in the training session. The main experiment included 16 problems of which half were given in manual mode and the others were in semi-manual mode. Also, among the 16 problems 8 were relatively simple (5 jobs, 4 machines) and the other 8 were much more complex (10 jobs, 8 machines). For simple problems, each job consisted of 2 - 4 operations , and for complex problems, 3 - 5 operations. Slack ratio was fixed to 1.5 in all the problems. In this experiment, the three performance measures were assigned the same weights, i.e., $\alpha=\beta=\gamma=0.33$.

3. Results and Discussion

It turned out that, for the simple problems, there was no significant difference between performance in the two modes. As the complexity increases, however, interesting results emerged. The results were summarized in figure 2 .

In training session, the performance in the semi-manual mode was better than that in manual mode. The subjects, when started with better initial solutions provided by the computer ended up with better final results. However, as

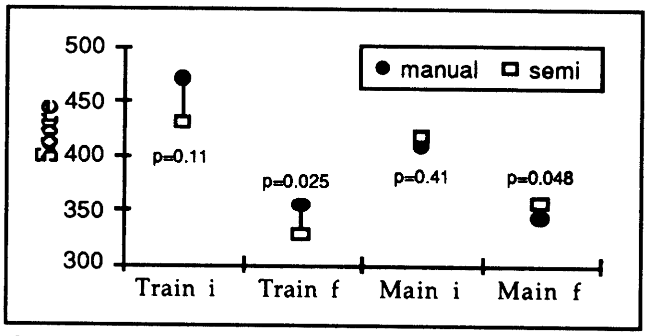

figure 2. Performance Scores in Complex Problems

the subjects developed enough expertise and strategies, they were able to construct as good initial solutions as the computer. More importantly the subjects performed better in the final schedules when they started with their own initial solutions. This result implies an important conclusion. That is, the continuity of strategy through problem solving stages plays an important role for achieving a good final schedule. In other words, the human seems to develop strategies that continue in both phases. One may think that, although it is statistically significant, the absolute difference in the performance was not great enough to practically concern. It may be true in many cases. But, as long as the phenomenon exists, it is reasonable to say that the magnitude and qualitative aspects of the difference may become more significant in some situations. Further research is called for in this regard.

A hypothetical explanation of this finding is that the pattern of the initial solutions given by the rules differed from what would have come out of the human strategies, and it increased the subjective complexity of the scheduler.

From the above results it can be said that when the human is a novice and the problem is relatively complex, it may be effective to aid him with good heuristics. However, once the human develops enough expertise to handle the complexity, the computer aid had better be something that support the continuity of human strategies form the initial phase of scheduling.

It is also worth investigating whether this conclusion can be extrapolated. That is, the human with a level of expertise may more appreciate the computer-generated initial solutions since he/she will be more of a novice when the complexity overloads.

As in the first experiment, every subject was superior to the best scoring rule in all problems as figure 3 shows. This result emphasized that an interactive approach to scheduling may have a strength over dispatching rules in multiple objective situations.

The result of the analysis of the correlation between initial and final performance score in manual mode shows that they are not correlated as suggested by the correlation coefficients, 0.46 overall and 0.51, 0.38, 043, 0.51 for each problem. However, we already confirmed that the two phases are strategically connected. Therefore, lack of correlation in scores should not be interpreted as saying the two phases are independent processes.

Conclusions

In this study, graphical interactive job shop scheduling environment was constructed and experiments using it suggested that the interactive or human-computer cooperative

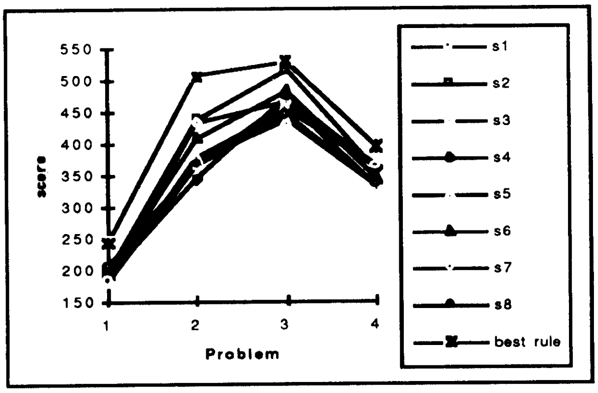

figure 3. Performance scores between the subjects and the best rule

scheduling is effective and promising. The graphical information aiding provided by the system also seemed to be very effective.

To capitalize the human cognitive ability or intelligence, it is crucial to design human-computer interaction that fits human strategies. This research showed how the continuity of human strategies affect the performance and that computer aiding that is incompatible to human information processing cannot be as effective as generally imagined. The results might be a first step to construct a jointly intelligent system in job shop scheduling. To attain more concrete principles, however, the behavior of real-world scheduling experts solving more practical problems should be studied.

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