Scheduling Jobs Considering Physiological Factors

1.1 Background

In the classical scheduling problem, the optimal sequence of jobs on a single machine is equivalent to the optimal sequence of jobs done by a single worker. But this is not the case in the real situation because the algorithm ignores constraints related to a human's physiological factors and limitations. Workers get tired both physically and mentally while they are doing their job. So, this situation cause reduced performance and productivity of the workers.

Fatigue is one important reason for decreasing workers performance. It can be caused by extended working hours, inadequate resting periods and unsuitable working conditions. According to Fatigue Management System Guidelines (FMSG), fatigued workers ability to perform their task, maybe lost or impaired. Workers who get fatigued can have

- Reduced motivation
- Decreased speed of task
- Increase in memory errors
- Inability to concentrate
- Incorrect action

Konz (1998) has declared that fatigue increases exponentially with time. Therefore, it is important to get rest before the fatigue level becomes too high. To prevent fatigue, workers need adequate resting periods during work periods. Breaks are designed to provide time for workers to overcome the fatigue arising from the work. Resting time can be classified by Konz and Johnson (2004) as formal breaks (lunch, coffee), informal break (interruptions, training) and micro breaks (short pauses of a minute). When a break is given, workers performance is expected to increase because of recovery. The recovery value is dependent with how fatigued the worker is when the rest begins and the length of the resting time. If the length of the break is small, the incremental amount of recovery is less than the incremental amount of time. For example, 4 breaks of 5 minutes are often more useful than 1 break of 20 minutes for two reasons; fatigue will not be increased as much and the recovery will be better.

In this study, we use rate- modifying activities (RMA) as a kind of resting activity for workers. RMA is first introduced in literature by Lee and Leon (2001). They defined RMA as an activity which alters the production rate of machines.

The RMA plays an important role in work-rest scheduling in the human factors literature. The main idea of work-rest scheduling is to obtain the number, place and duration of rest periods. While determining those decisions, productivity, safety and comfort are considered.

In literature, the objectives of the work-rest problem are to minimize fatigue and to provide recovery of the worker while not reducing productivity. Boucsein and Thum (1997) found that short breaks are more effective in promoting recovery from both mental and emotional ways to workers**.** Table 1.1 shows that several researchers studied the work-rest problem for various physiological variables such as heart rate, blood pressure, oxygen uptake and electromyography (EMG) signals. They found that resting time is important to recover from fatigue.

Table 1.1 Work-Rest Problems

Veltman and Gaillard (1993)	Heart rate, blood pressure
Boucsein (1993)	Heart rate variability (HRV), EMG signals, electro dermal activity
Imbeau et al. (1995)	Heart rate, Maximum aerobic capacity (%VO2 Max)
Wu and Wang (2002)	%VO2 Max, heart rate
Tiwari and Gite (2006)	Heart rate
Hsie et al. (2009)	%VO2 Max

Our model is extends the first model which is in chapter one. The first model is to determine the work sequence, the number of breaks and the place of each break without considering the physiological factors of the worker. In this study, we consider the human characteristics while determining the work sequence, the number of breaks and the optimal break schedule.

This study differs from existing research in several ways. First, we define rate- modifying activities as resting period of workers; whereas all other studies use rate-modifying activities as machine maintenance and repair time. Second, there is no research that considered the workers physiological factors when scheduling the jobs. Third, in our study, deteriorated jobs are caused by fatigue of the worker, but in literature, jobs deteriorate while waiting to process. To the best of our knowledge, there is no research that proposed a task sequencing approach which combines with deteriorating jobs, RMA and considers the human characteristics.

In the next section, we discussed the new model. In section 1.3, we present an extended mathematical model. Algorithms are in section 1.4. Special cases are presented in Section 1.5. We offer conclusions in section 1.6.

1.2 Discussion of New Model

This chapter is motivated by the problem of manual order picking activities in warehousing systems. The problem is to determine the sequence in which the orders should be picked in minimum time and within acceptable levels of human physiological factors. In addition, breaks can be scheduled to allow workers to recover in the middle of the order picking sequence. We consider sequencing n orders (jobs) on a single worker (processor) with varying processing speed due to the effects of various ergonomic factors. We assume that a break or maintenance activity can be scheduled to improve the processor state any time after the first task is scheduled.

In our first mathematical model, we determined the optimal job sequence with the optimal number of breaks and the place of each break. But that model lacks considering human's physiological factors for the worker. Therefore, we added new constraints which relate to a human's physiological factors to calculate the optimal job schedule for a single worker.

For this new model, we can include a physiological factor which affects the worker's performance. Also, the usage of jobs and recovery rate affects the solution when compared to the result of the first model. The new model gives more total completion time or makespan value than the first model because of the changing recovery rate. In the new model, the worker doesn’t recover completely. The job, which is already deteriorated, deteriorates again even if there is an RMA before that job. Thus, this increases the realized processing times of jobs and then total completion time. Additionally, this also affects the number of RMA to be given by the new model.

1.3 Extended Model

The new mathematical model decides the sequence in which jobs should be scheduled, how many breaks to use to avoid fatigue, if any, and where to use them in the schedule. Those decisions are affected by human factors such as heart rate, oxygen consumption, and blood pressure. The main difference of this model from the first one is that the worker doesn’t recover completely, which means there is not 100% recovery of his/her lost energy and other factors, after a break (RMA). Hence, in this model we assume that every job consumes worker’s physiological capacity in some level. Hence, the recovery rate changes with the position of job when it is done. Also the types of jobs are affected the recovery rate of the worker. Heavy jobs need more effort than light jobs.

Assumptions

- Breaks should be taken during work shifts.
- The worker doesn’t recover completely after breaks.
- Consider at least one physiological factor.
- Worker can not process two or more jobs simultaneously.

Parameters

r_f Recovery rate of physiological factor *f*,

a_{fj} Usage rate of physiological factor *f* by job *j*,

s_{fi} Change in cumulative physiological factor *f* caused by the i^{th} RMA,

$\underline{R}_f\left(\overline{R_f}\right)$ A lower (upper) limit on physiological factor *f*

Decision Variables

R_{fi} Cumulative value of physiological factor *f* at position *i*,

Additional Constraints

$$R_{f1} \geq \sum_{j=1}^{n} \left(r_f - a_{fj}\right) p_{j1} x_{1j0} \tag{1.9}$$

$$R_{fi} \geq R_{f,i-1} + \sum_{k=1}^{i} \sum_{j=1}^{n} \left(r_f - a_{fj}\right) p_{jk} x_{i,j,i-k} + s_{fi} y_i \qquad i = 2,.....,n \quad f = 1,.....,F \tag{1.10}$$

$$\underline{R}_f \leq R_{fi} \leq \overline{R}_f \qquad i = 1,.....,n \quad f = 1,.....,F \tag{1.11}$$

(1.9) Constraints compute the cumulative level of physiological factor α of the worker at the end of position 1.

(1.10) Constraints compute the cumulative level of physiological factor α of the worker at the end of position *i*.

(1.11) The level of cumulative physiological factor α is always within prescribed acceptable limits.

Performance of the Extended Model

A computational experiment is conducted to test the performance of the new model. To conduct our analyses on the proposed models, we identify four experimental factors: deterioration rate (α), RMA time (*q*), mean of processing time (*M*) and variance on mean of processing time (*V*). Also, we specify three levels for each factor. So, this is called 3^4-experimental design with six two-factor, four three- factor interactions and one four-factor interaction. The defined levels of those factors in the experiments are given below.

1) α : 0.02, 0.04 and 0.08
2) q : 5, 10 and 15
3) M : 20,40 and 80
4) V : 0.20, 0.40 and 0.80

Using the variance on mean of processing time, we produced an interval for mean of processing time of which it is assumed to be uniformly distributed. These are [18, 22], [10, 30], [1, 40], [36-44], [20-60], [1-80], [72-88], [40-120], [1-160]. As we mentioned before, the processing time of a job in different positions is calculated using $p_{ji} = (1+\alpha)^{i-1} p_j$. Besides, we test our models for 50 jobs and 810 instances are run for each experiment. In the extended model, we use three different physiological factors which are oxygen consumption ($VO_{2\max}$), heart rate ($HR_{\max}$) and blood pressure (BP). The new parameters are generated from uniform distribution.

Table 1.2

Physiological factors	**Recovery rate (r_f)**
$HR_{\max}$	r_f ~U[1-20] %
$VO_{2\max}$	r_f ~U[1-15] %
BP	r_f ~U[1-20] %

Table 1.3

Physiological factors	**Usage rate (a_{fj})**
$HR_{\max}$	a_{fj} ~U[1-15] %
$VO_{2\max}$	a_{fj} ~U[1-15] %
BP	a_{fj} ~U[1-15] %

Table 1.4

Physiological factors	**Changes based on factors (s_{fi})**
$HR_{\max}$	s_{fi} ~U[1-10] %
$VO_{2\max}$	s_{fi} ~U[1-10] %
BP	s_{fi} ~U[1-10] %

Table 1.5

Physiological factors	**Acceptable limits (** $\underline{R}_f\left(\overline{R_f}\right)$**)**
$HR_{\max}$	160 bpm- 220 bpm
$VO_{2\max}$	15 % - 33%
BP	75 mmHg -115 mmHg

The proposed model is also coded using AMPL and solved by CPLEX 9.1 on a computer with Pentium IV 2.8 GHz processor and 1GB of RAM. Again 81 replications were run for total completion time objective function. The average computation times are given in Table 1.6 and Table 1.7.

Table 1.6 Average Run Time for Total Completion Time (sec.)

Det. Rate	0.02			0.04			0.08		
RMA time	5	10	15	5	10	15	5	10	15
Run Time	33.7	42.5	59.8	31.9	37.2	51.9	18.1	28.2	43.7

Table 1.7 Average Run Time for Makespan (sec.)

Det. Rate	0.02			0.04			0.08		
RMA time	5	10	15	5	10	15	5	10	15
Run Time	41.2	47.9	54.5	38.3	46.4	51.4	18.3	29.9	48.1

The efficacy of the model is based on the average run time in seconds. The average time for total completion and the makespan problem is 38.55 seconds and 41.7 seconds. The run time for the problem of minimizing total completion time decreases, when deterioration rate increases. Also, it increases when RMA time goes up. These results are the same as the result for the first model. Hence, we say the new model is consistent. When we compare the run time, the extended model is faster than previous model. Because now we have more constraint and our feasible region gets smaller. After 90 replications, the main difference between the first model and the extended new model is the place of the breaks. This is what we expected because in the extended model we consider the workers physiological factors. As a result, the extended new model reflects a real industry situation.

1.4 The Heuristic Algorithm

In this section, we now give a polynomial time algorithm for the problem $1| p_{ij} = (1+\alpha_j)\, p_j, rm, | C_{\max}$ with considers to physiological factors of workers.

The general problem is known as $NP-hard$. In order to solve it we have developed a heuristic algorithm which is given in the below. Santos and Resnick (2005) developed an equation which calculates worker's predicted fatigue rate. We use fatigue as the single physiological factor, other factors could be used as well.

The parameters and the equation are given below;

$$Fatigue(F) = -2.25 + 0.63t + 0.53m + 0.08p$$

$m =$ The mass of the handled load in kg
$t =$ The time into shift in minutes
$p =$ The production rate in units per minute

In the proposed heuristic model, we first provide the worker's basic information such as gender, age, height and weight. Then, sort the jobs according to SPT rule. The job which has the largest processing time is assigned to position 1. After assigning the job, then calculate fatigue rate of the worker which is equal to worker's physiological capacity. Fatigue can be used as an upper limit for energy expenditure during the work. According to Borg scale, determine upper limit. If this amount is bigger than acceptable limits, then do an RMA and assign the next largest job to the current position immediately after the RMA. Otherwise assign the smallest job to the current position without doing an RMA. Stop the heuristic when all jobs are assigned all positions.

The procedure is described as follows:

Step 1 Determine the basic information that will be used in other step.
(e.g. mass of the load, production rate and time)

Step 2 Number the jobs in SPT order.

Step 3 Schedule the job with largest processing time to position one and no RMA at the beginning.

$R_{[1]} = 0$, $J_{[1]} = n$

Set $C_{[1]} = P_{n[1]}$

$b = n - 1$ and $s = 1$

Step 4 For $k = 2 \ldots n$

Calculate the $Fatigue$

$$Fatigue(F) = -2.25 + 0.63t + 0.53m + 0.08p$$

Step 5 Determine the acceptable limit of worker's fatigue.

Step 6 if fatigue is within the acceptable limits or not.

If $F <$ acceptable limit $(\underline{R}_f)$

Then;

$R_{[k]} = 0$, $J_{[k]} = s$

Set $C_{[k]} = C_{[k-1]} + P_{b[m]}$,

$s = s + 1$ and $\mathrm{m} = \mathrm{m} + 1$

Otherwise go to step 7.

Step 7 $R_{[k]} = 1$ (give RMA), $J_{[k]} = b$

Set $C_{[k]} = C_{[k-1]} + P_{b[1]} + q$,

$b = b - 1$ and $\mathrm{m} = 1$

If $k < n$ Go to Step 4.

Otherwise go to Step 8.

Step 8 If $k = n$, Stop the algorithm, Makespan $= C_{[n]}$.

1.5 Numerical Example of Heuristic

In this section, we use several numerical examples to illustrate the behavior of the model. In all the examples we assume the following parameters values which is seen in Table 1.8 and Table 1.9.

Table 1.8 Basic information

Mass of the hand load	U~[3-20] kg
Time into the shifts	U~[1-10]minutes
Production Rate	U~[1-10]unit /minute

Table 1.9 Experimental factors

Factors	Levels
Number of jobs	10, 25, 50
Processing time	U~[10-100]
Deterioration rate	0.04, 0.06, 0.08
RMA time	5, 10, 15

For larger problems, we compare heuristic solution with a random solution which is a solution taken randomly from the solution sets. We use following equation;

$$e = \frac{F_h - F_r}{F_r} * 100\%$$

In this equation, F_h is the makespan value of the heuristic model, F_r is the makespan value of the random solution which is selected randomly from the set of heuristic solutions and e is the average performance of the heuristic.

The heuristic is replicated 10 times for each problem cases and it developed by JAVA with Pentium IV, 2.8 GHz processor and 1GB of RAM.

When we test our models for 10 replications for each specific set of conditions, we obtain the average percentage error of the heuristic model which is given in the Table 1.10.

Table 1.10 Comparison of Heuristic and Mathematical Model for Total completion for one factor

Number of jobs	**α**	**RMA time**	**Ave. Error of Heuristic (%)**
10	0.04	5	0.13
		10	0.32
		15	0.24
	0.06	5	0.33
		10	0.13
		15	0.23
	0.08	5	0.45
		10	**0.92**
		15	0.51
25	0.04	5	0.19
		10	0.54
		15	0.44
	0.06	5	0.69
		10	0.63
		15	0.16
	0.08	5	0.48
		10	0.58
		15	0.31
50	0.04	5	0.32
		10	0.17
		15	0.60
	0.06	5	0.41
		10	0.14
		15	0.48
	0.08	5	0.37
		10	0.18
		15	0.19

Table1.11 Comparison of Heuristic and Mathematical Model for Makespan for one factor

Number of jobs	**α**	**RMA time**	**Ave. Error of Heuristic (%)**
10	0.04	5	0.34
		10	0.96
		15	1.05
	0.06	5	0.45
		10	0.92
		15	1.78
	0.08	5	1.02
		10	1.59
		15	1.54
25	0.04	5	0.79
		10	1.17
		15	1.81
	0.06	5	0.94
		10	1.63
		15	1.6
	0.08	5	1.08
		10	1.37
		15	1.42
50	0.04	5	0.62
		10	0.90
		15	1.25
	0.06	5	0.91
		10	1.43
		15	**1.98**
	0.08	5	1.37
		10	1.84
		15	1.93

Ave:1.24

3.6 Summary

In this study, we studied a scheduling problem with deterioration jobs and RMA simultaneously with consider to physiological factors.

Firstly, we present a mathematical model with the objective of minimizing the makespan and total completion time. Our model can decide the sequence of jobs in which jobs should be scheduled, how many RMAs to use, if any, and where to use them in the schedule. Those decisions are affected by human factors such as heart rate, oxygen consumption, and blood pressure.

Secondly, we propose a heuristic model for makespan. Then, we present some computational experiments. According to the experiment results, the performance of the proposed model and the heuristic are quite satisfactory. We show that, when the number of jobs increases the computational time to solve the problem increases dramatically for the mathematical model. Besides, the heuristic model gives a reasonable error for 50 jobs when compared to the mathematical model.

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