PAPER DETAILS

TITLE: Bir Isçi Tarafindan Bakilan Bir Grup Makinanin Verimliliginin Hesaplanmasi Için Matematiksel Bir Yaklasim

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PAGES: 220-237

ORIGINAL PDF URL: https://dergipark.org.tr/tr/download/article-file/137766

Bu sayının okurlarımızın eline geçtiği sırada TMMOB Makina Mühendisleri Odası'nın dergimiz önderliğinde düzenlediği ve başarılı olacağına yürekten inandığımız IV. Tekstil Sempozyumu gerçekleşmiş ve Sempozyum Özel Sayısı da genel dağıtıma sunulmuş olacaktır. Tekstilin tüm alanlarındaki çeşitli bilimsel araştırma ve gelişmeleri yansıtan, önemli yorum ve değerlendirmeleri içeren bildirilerin yayınlanmasından sonra bu sayımız da araştırma yazıları ağırlık taşıyan bir kapsamda okurlarımıza sunulmaktadır. Kuşkusuz bu sevindirici bir durumdur.

Araştırmaların ülkelerin kalkınmasına büyük ivmeler kazandıran teknolojik gelişmelerin altyapısını oluşturduğu bir gerçektir. Özellikle temel ve uygulamalı bilim alanlarında sürdürülen araştırma çalışmaları hem teknolojik gelişmelere yol açmaları hem de bu gelişmeleri gerçekleştirecek bilim adamları, mühendisler ve uzmanların yetişmelerindeki büyük ve kaçınılmaz işlevleri bakımından önemlidir. Ülkemiz tekstil çevresinde de böyle bir araştırma potansiyelinin varolduğunu görmek ülkemizin ve toplumumuzun kalkınması açısından geleceğe dönük yeni umutlar yaratmaktadır.

Daha önceki sayılarımızda yer alan sunuş yazılarında da belirttiğimiz gibi Tekstil ve Makina Dergisi'nin içeriği gelen yazıların tür ve konuları ile oluşmaktadır. Araştırma yazılarına olduğu kadar endüstriyel uygulamalara, teknolojik gelişmelere ışık tutan yazılara da bize ulaşan yazı akımı içinde ve yazıların içerik zenginliği ölçüsünde yer vermek ilkesini uyguluyoruz. Bunu yaparken dergimizde endüstriyel uygulamaları, bulguları, pratik bilgileri özlü biçimde aktaran KISA BİLDİRİLER BÖLÜMÜ açtığımızı da belirtmiştik. Değerli yazar ve okurlarımızın bu tür yazılarını da bekliyoruz.

Gerek Sempozyum Özel Sayısı'nda yer alan ve yurt dışından gelen bildiriler, gerekse bu sayımızda da olduğu gibi, yurt içindeki yazarlar tarafından sunulmuş olmakla birlikte orjinal olarak yabancı dilde yazılmış olan araştırma yazıları bir ölçüde Tekstil ve Makina Dergisi'ne uluslararası bir yayın organı olma niteliğini de kazandırmaktadır. Bu çerçevede dergimize yurt dışından da yazı akışı olacağı anlaşılmaktadır. Türk araştırmacılar tarafından orjinali yabancı dilde yazılmış yazıları yayınlamaktaki amacımız bilimin evrenselliğini gözeterek Türk araştırmacılarla yabancı araştırmacılar arasında iletişim kurulmasına katkıda bulunmak ve ülkemizin tekstil alanındaki potansiyelini dış dünyaya daha güçlü biçimde duyurmaktır.

Dergimiz üstlendiği görevin ve oynadığı rolün bilincinde sürekli arayış ve gelişme içinde varlığını sürdürmektedir.

Saygılarımızla
YAYIN KURULU

1. INTRODUCTION

The calculation or the prediction, rather, of machine efficiency when an operative tends a group of machines is an important problem of production management. It is especially so in the textile industry as an operative is usually in charge of several machines or of several production units mounted on a common frame such as in a spinning machine. A unidirectional patrolling is the usual practice when the number of machines attended is very high.

A theoretical approach to the problem becomes imperative in situations such as in fixing piece rates. It is not practical to make an experimental determination of the machine efficiency by assigning a new and higher number of machines to the operative. Objective measurements are difficult to make and in most cases there will be psychological resistance to such an experimentation. As this is a well-known problem, many investigators have tackled the general problem of several machines under the care of one or more operatives, the problem of machine interference in particular.

Ashcroft (1950), by a statistical approach, calculated the average number of machines running, assuming that breakdowns ocurred at random in time and equal times were required for the repair of each failure. He also examined the case when the repair times had an exponential distribution function, but he did not taken into account the walking time between successive repairs.

Benson and Cox (1951) examined the problem in greater detail for distributed repair times, assuming that the operative attended the machines in the order in which they stopped. The way the operative patrols the machine and the effects of the walking time between the broken down machines were dealt with first by Brunnschweiler (1954). Mack et al (1957) discussed the problem of unidirectional patrolling when walking time and repair times were assumed to be constant and gave a table of running efficiencies. Bunday and Jackson (1975) dealt with the problems of both unidirectional and bidirectional patrolling for variable repair times by applying simulation techniques. They generated the distribution function of repair times on a computer and calculated the efficiency of up to 28 machines under varying conditions which depended on the number of breakdowns per machine and on the walking time.

Jones (1963) treated the problem of random servicing of several machines by one operative by calculating the machine interference itself from the work load. He used the Binomial model and assumed that the operative walked an average distance each time to repair a broken down machine.

The method of approach to the problem is statistical in all the abovementioned treatments. O'Connor (1965) looked into the problem of unidirectional or cyclic servicing from a different angle however, and aproached the problem mathematically. He considered the effect of the operative's work for a stopped machine on the other machines and wrote down equilibrium conditions. His solution, however, involved an iterative process by assigning an initial value to efficiency. A theoretical attempt was made by Güngör (1967) on the same lines, who took into account the events occurring in an interval dt of a working cycle and derived a differential equation for the number of machines stopping at any time.

In a previous work [Başer, 1972-1] the author also approached the problem mathematically by considering what exactly happens to machines when the operative works in a certain way and derived an interference formula for the case of random servicing. An attempt was also made [Başer, 1972-2] to apply this formula in the treatment of the problem of cyclic servicing which did not however prove to be very practical.

What has been lacking in all these investigations is experimental work to verify the formulae derived and a general analysis of the axact behaviour of man-machines system under the varying conditions relating the method of working and the way the machines are arranged. It has, therefore, been the aim of this work to tackle the problem, that of unidirectional attendance in particular, analytically by constructing a mathematical model. It has also been the aim to make actual measurements of machine interference and efficiency by the stop-watch time study techniques to verify the theories.

2. THEORY FOR UNIDIRECTIONAL ATTENDANCE OF SEVERAL MACHINES BY ONE OPERATIVE

In weaving, a number of looms may be tended either randomly or by patrolling in a certain path whereas in the attendance of spinning machines the method of walking is always regular in either unidirectional or bidirectional way. As the number of machines tended by one operative is high and great walking distances are involved, regular attendance becomes imperative irrespective of the type of machine.

What is happening when an operative attends several machines by walking in a certain path may be described as such: The operative will walk along and service the broken down machines one after the other, completing his or her tour in a certain time. The operative may do other useful work at the running machines but will give priority to the stopped machines. In such servicing the period of one tour will depend on the frequency of stoppages as well as the walking speed of the operative.

At the onset of a working period, the time of one cycle of the operative round the machines under his or her care may vary from cycle to cycle. After a certain time has elapsed, however, a steady state will develop where the operative is in equilibrium with the machines. That is to say, the operative will set his walking and working rate to complete his or her tour round the machines in a theoretically fixed time. The number of the stopping machines at any instance will also reach a constant value, on the other hand, starting with an initial value of zero at the begining of a working period at which all the machines are running. Thus the number of machines stopping as a function of time may be expected to be a periodic function which is damped out at a certain level when the steady state conditions are obtained.

In developing a theory according to the above described model of man-machines system, we may assume that the walking rate is constant and no work is done other than reparing the broken down machines for simplicity.

Let us assume that breakdowns occur in a machine at an average rate of f per unit time, the time taken by the operative to walk from one machine to the next is w and that the repair time of a broken down machine is z.

If in the steady state conditions the number of machines stopping at agiven instance is n and the number of machines assigned to one operative is N, then (N–n)f dt new stoppages will occur in an interval of time dt. In the same interval of time, the operative will repair some machines.

The time taken by the operative to repair one machine will be obtained by the sum of the repair time and the walking time from one stopping machine to the other. This time will, on the average, be dt/(Nw/n + z) and thus the increase dn in the number of machines being at a stop at any time will be given by

$$dn = (N - n)\, f\, dt - dt/\, (Nw/n + z) \quad \text{........................} \quad (1)$$

Equation (1) may be arranged as a differential equation of the form,

$$\frac{dn}{dt} + \frac{Nw+zn}{zfn^2 + [1 - fN\,(z-w)]\, n - wfN^2} = 0 \quad \text{...........} \quad (2)$$

Substituting the values

$A = wN$
$B = z$
$a = -zf$
$b = -[1 - fN\,(z-w)]$
$c = wfN2$

and on integrating ,Equation (2) has a solution

$$A\int \frac{dn}{an^2+bn+c} + B\int \frac{ndn}{an^2+bn+c} = t + C \quad \text{.........} \quad (3)$$

where C is a constant. Solving the integrals in Equation (3) and applying the boundary conditions n = 0 when t = 0 to solve for C, the equation,

$$t = \left(a - \frac{bB}{2a}\right)\frac{1}{a\,(p-q)}\log\left|\frac{(n-p)\,q}{(n-q)\,p}\right|$$

$$+\frac{B}{2a}\log\left|\frac{an^2+bn+c}{c}\right| \quad \text{....................................} \quad (4)$$

is obtained when $b^2 > 4ac$, where p and q are the roots of the quadratic $an^2 + bn + c$. For the case when $b^2 < 4ac$ the equation takes the form,

$$t = \left(A\frac{bB}{2a}\right)\frac{2}{\sqrt{(4ac-b^2)}}\left[\tan^{-1}\frac{2an+b}{\sqrt{4ac-b^2}} - \tan^{-1}\frac{b}{\sqrt{4ac-b^2}}\right]$$

$$+\frac{B}{2a}\log\left|\frac{an^2+bn+c}{c}\right| \quad \text{....................................} \quad (5)$$

These equations give the time t in terms of the number of stopping machines n and therefore not suitable to investigate the variation of n from the start of a working period until a steady state is reached where the number of the stopping machines reamins constant. However,by applying the steady state condition that

$$\frac{dn}{dt} = 0, \qquad n = n_o$$

the number of machines stopping at any time may be obtained by the roots p and q of the quadratic function $an^2 + bn + c$ as,

$$n_o = -\frac{1}{2zf}\left\{1 - fN(z-w) \pm \sqrt{[1-fN(z-w)]^2 + 4zwf^2N^2}\right\} \quad (6)$$

2.1. Machine Efficiency

The machine efficiency E may be simply expressed as

$$E = 1 - n_o/N \quad (7)$$

2.2. Cycle Period

The period of one cycle, τ, at the end of which the operative returns to the starting point may be obtained by the sum of the walking time per cycle and the time spent by the operative to repair the machines stopping. If the machines repaired per cycle is n_1, then the cycle period τ is given by

$$\tau = wN + n_1 z \quad (8)$$

2.3. Number of Machines Repaired per Cycle

In steady state conditions there will be n_o machines stopping at any time and thus $N-n_o$ machines will be in the running state. In each cycle the operative will have to repair n_o stopping machines plus those machines that are likely to break down during the cycle period τ, which lie ahead of the operative. Since it may be assumed equally likely that breakdowns will occur both in front and behind the operative (i.e. between the operative and the starting point of a cycle in two opposite directions), the operative will tend only half of the machines broken down in the course of one cycle, which lie ahead relative to the starting point. Thus the number of machines to be repaired in the course of one cycle, n_1, will be

$$n_1 = n_o + \frac{1}{2}(N - n_o) f \tau \quad (9)$$

Substituting Equation (9) in Equation (8) the cycle period τ will be obtained as

$$\tau = \frac{wN + zn_o}{1 - \frac{1}{2}(N - n_o) fz} \quad (10)$$

With Equations (6), (7) and (10), all the important parameters that will be useful in an analysis of unidirectional or cyclic service of N machines by one operative are, thus, theoretically definable.

3. EXPERIMENTAL WORK

3.1. General Method of Experiment

The method adopted in the experimental work was to make a more comprehensive time study than usual, of a particular process while a given number of machines were being attended by one operative working in a standard way. The special technique applied in this time study included the observation and timing of each breakdown occuring in a succession of machines which were next to each other and whose number was so chosen as to allow easy and accurate observation. Those breakdowns which occurred spontaneously were also noted down when possible. Thus, it was hoped to measure the actual loss of production time due to both the time spent to repair breakdowns and the time lost due to machine interference. The repair times were, however, studied separately by the work measurement technique. Separate measurements were carried out for each type of repair.

The same attitude was taken for the walking time between breaks as well as for other useful work done by the operative when the machine was runing. In the cases of regular attendance the cycle periods for each run were timed several times by the stopwatch. The working rates of the operatives were evaluated as the overall rate of each operative taking part in the experiment.

The actual productions achieved during the course of the time studies were also determined as the net weights of single doffs from a given number of machines. The purpose was to compare the actual productivity calculated on the basis of time units with that calculated on the basis of direct measurement of production and production rate.

3.2. Experiments of Regular Attendance

Two experiments were carried out applying the method explained above inasmuch as it was possible, one being on a Zinser ring spinning frame working a 26/2 Nm worsted yarn, another on a Gilbos winding machine working a 36/2 Nm worsted yarn. Unidirectional patrolling was applied by the operatives in the spinning machine whereas in the winding machine bidirectional patrolling was the only way since the operatives were given the care of 25 bobbin heads which were on one side of the machine frame.

The particulars of the complete time study measurements are given in Tables I and II for the spinning and winding machines respectively. Four studies on spinning machines, five studies on the winding machine were done. As it is intended to verify the theory by the experimental results of productivity, all elementary times in Tables I and II are shown as the actual times achieved in the actual working rates.

Table 1: Results of the Time Studies Carried out on the Zinser Spinning Frame

Material Properties				
Yarn count : 26/2 Nm				
Twist : 430 t.p.m.				
Blend : 50 % Domestic wool, 30 % Viscose staple, 20 % Polyester				
Conditions of the Time Studies				
Number of spindles/operative	: 400			
Number of spindles studied	: 20			
Number of time studies carried out	: 4			
Distance between spindles	: 10.25 cm			
Diameter of front rollers	: 35 mm			
Time Study Results				
	Study 1	Study 2	Study 3	Study 4
Duration of the time study (min)	120	120	120	120
Number of revolutions of front rollers (rev/min)	146	146	148	150
Working rate (%)	95	90	90	90
Yarn count measured (Nm)	25.5	25.4	25.6	25.9
Production time of a full set of cops (min)	168	160	162	157
Amount of production (net Kg/400 spindles)	39	37	38.5	38.5
Total break frequency of the spindles (breaks/20 spindles)	7	4	8	7
Total stoppage time of the spindles (min/20 spindles)	12.93	7.94	13.29	13.12
Number of interferences	2	0	2	1
Number of stoppages with interference	4	0	4	2
Average cycle period	: 2.40 min			
Walking time between two spindles	: 0.00225 min			
Average walking time between two stoppages	: 28.3 centi-min			
Standard piecing time	: 12.2 centi-min			
Standard time for roving feeding and piecing	: 40 centi-min			
Standard time for change of bobbin and piecing	: 48 centi-min			

The evaluations of the experimental results obtained and given in Tables I and II are shown in Tables III and IV for the spinning and winding experiments respectively. Estimates of the actual total stopping time for the number of spindles or winding heads were made as the weighted averages obtained by taking all the separate studies together. The automatic times were then calculated by the subtraction of this value from the total working time. The break frequencies were also calculated as the weighted averages, as the ratio of the total break frequency to the total automatic time.

The average repair times per stop were calculated from the standard repair times given in Tables I and II, which themselves were evaluated by the work measurement technique, as the weighted averages corrected for the actual working rates. The process of weighting was based for the spinning experiment on a composition of 96 % normal piecing and 4 % feeding of roving and piecing or change of roving bobbin and piecing as the calculated percentages giving an average time of 44 centi-minutes for the latter type of piecing. For the winding experiment the actual composition of the various types of breaks was used for the weighting of the repair times to find the average repair time at actual working rate.

The actual productivity is obtained by diving the automatic time by the working time (automatic time + total stopping time). The productivity is also calculated on the production basis by dividing the actual production rate by the theoretical value.

Table 2: Results of the Time Studies Carried out on the Gilbos Winding Machine

Material Properties					
Yarn count : 36/2 Nm					
Twist : 430 t.p.m.					
Blend : 45 % Merino wool, 55 % Polyester					
Conditions of the Time Studies					
Number of heads/operative	: 25				
Number of heads studied	: 5				
Number of time studies carried out	: 5				
Distance between heads	: 33.4 cm				
Diameter of winding drum	: 70 mm				
Number of revolutions of the drum	: 2750 rev/min				
Winding angle	: 17.5°				
Time Study Results					
	Study 1	Study 2	Study 3	Study 4	Study 5
Duration of the time study (min)	39	42	40	41	41
Working rate (%)	95	95	90	100	90
Yarn count measured (Nm)	17.2	17.2	17.6	17.5	17.4
Amount of production (net Kg/25 h.)	29.6	31.3	29.5	31.6	28.3
Total break frequency of the heads (breaks/5 heads)	38	42	42	41	43
– Piecing	3	2	2	1	3
– Change of cop and piecing	30	35	35	35	35
– Bobbin doffing	5	5	5	5	5
Total stoppage time of the heads (centi-min/5 heads)	2186	1965	3566	1725	3339
– Piecing	474	222	212	61	151
– Change of cop and piecing	1417	1464	3072	1281	2364
– Bobbin doffing	295	279	282	283	824
Standard piecing time	: 10 centi-min				
Standard time for change of cop and piecing	: 12 centi-min				
Standard time for bobbin doffing	: 17centi-min				
Average cycle period	: 136.7 centi-min				
Average walking time between two heads	: 0.00076 min				
Average walking time between two stoppages	: 0.763 centi-min				

Table 3: Evaluation of the The Studies Carried out on the Zinser Spinning Frame

Number of Machines assigned = N	: 400 spindles
Total stoppage time	: 0.788 h/20 spindles
Total automatic time	: 159.2 h/20 spindles
Productivity (on time basis)	: 99.51 %
Theoretical production rate	: 16.22 m/min/spindle
Actual production rate	: 15.14 m/min/spindle
Productivity (on production basis)	: 93.33 %
Average break frequency = f	: 0.163 breaks/h/spindle
Average repair time = z (actual working rate)	: 14.78 sec = 0.00411 h
Average cycle period = τ	: 2.40 min (0.04 h)
Average walking time between two spindles = w	: 0.00225 min (0.0000375 h)
Average walking time between two stoppages = Nw/n_o	: 0.283 min (0.00047 h)

Table 4: Evaluation of the Time Studies Carried out on the Gilbos Winding Machine

Number of Machines assigned = N	: 25 heads
Total stoppage time	: 2.114 h/5 heads
Total automatic time	: 14.88 h/5 heads
Productivity (on time basis)	: 87.56 %
Theoretical production rate	: 634.4 m/min/head
Actual production rate	: 512.2 m/min/head
Productivity (on production basis)	: 80.73 %
Average break frequency = f	: 13.89 breaks/h/head
Average repair time = z	: 13.32 sec = 0.0037 h (actual working rate)
Average cycle period = τ	: 1.368 min (0.0228 h)
Average walking time between two spindles = w	: 0.0076 min (0.000127 h)
Average walking time between two stoppages = Nw/n_o	: 0.763 min (0.0127 h)

Table 6: Evaluation of the The Studies Carried out on the Schweiter Doubling Machine

Number of machines assigned = N	: 6
Total stoppage time = Σt_d	: 3710 centi-min / 3 heads
Total working time = ΣT	: 59100 centi-min / 3 heads
Total automatic time = Σt_m	: 55390 centi-min / 3 heads
Actual productivity (on time basis)	: 93.72 %
Total stoppage time without interference (at actual working rate)	: 2479.5 centi-min / 3 heads
Average break frequenay = $\bar{f}$	: 18,35 breaks/spindle/h
Average stoppage time (at actual working rate) = $\bar{t}_d$	: 14 centi-min (0.00233 h)
Average repair time (including walking at actual working rate) = $\bar{t}_d + \bar{t}_y$	: 19.6 centi-min (0.00327 h)
Average probability of a stoppage at a single machine = $\bar{p} = \bar{f}\,(\bar{t}_d + \bar{t}_y)$	: 0.06
Productivity of single machine	: 99.96 %
Total time of stoppages with interference	: 1230.5 centi-min / 3 heads
Total interference loss	: 485.7 centi-min / 3 heads
Average interference = $\dfrac{\text{Total interference loss}}{\text{Total working time}}$ = G	: 0.0082
Actual production	: 338.1 m/min/head
Theoretical production rate	: 342 m/min/head
Productivity (on production basis)	: 98.85 %

Table 5: Results of the Time Studies Carried out on the Schweiter Doubling Machine

Material Properties

Yarn count	: 32/2 Nm
Twist	: 430 t.p.m.
Blend	: 70 % Merino wool, 30 % Polyester

Conditions of the Time Studies

Number of heads	: 12
Number of heads/operative	: 6
Number of heads studied	: 3
Number of time studies carried out	: 5
Distance between heads	: 30 cm
Diameter of winding drum	: 76 mm
Number of revolutions of the drum	: 1362 rev/min
Winding angle	: 18°

Time Study Results

	Study 1	Study 2	Study 3	Study 4	Study 5
Duration of the time study (min)	36	35	46	39	41
Number of the revolutions of the drum (rev/min)	1303	1303	1423	1380	1380
Working rate (%)	95	95	100	90	90
Amount of production (net g)		4500	4450	5940	5190
Total break frequency of the heads (breaks/3 heads)	37	30	36	39	35
– Bobbin unwiding and piecing	0	1	1	0	0
– Clearing neps	12	6	11	9	8
– Change of cop and piecing	17	15	19	20	18
– Piecing	8	8	5	10	9
Total stoppage time of the heads (centi-min/3 heads)	771	728	617	872	722
– Bobbin unwinding and piecing	0	43	27	0	0
– Clearing neps	160	140	112	132	109
– Change of cop and piecing	433	338	410	504	380
– Piecing	178	207	68	236	233
Number of interferences	2	1	5	6	4
Number of stoppages with interference	4	2	12	13	7
Total time of stoppages with interfrence centi-min	99	68	318	339	220

Standard time for bobbin unwinding and piecing: 64.3 centi-min
Standard time for neps clearing : 5.3 centi-min
Standard time for change of cop and piecing : 17.7 centi-min
Standard piecing time : 14.5 centi-min

3.3. Experimentson Random Attendance

The experiment was carried out on a Schweiter doubling frame working a 32/2 Nm worsted yarn. Five time studies were done and great care was taken to measure the stoppages at each of the winding heads under observation. The spontaneously occurring stoppages were carefully noted down. The particulars of the time study measurements thus carried out are shown in Table V. The evaluations of these measurements were done in a similar way to those for the experiments on regular attendance case. The evaluated results are shown in Table VI. Some of the symbols to be used in the theoretical calculations feature also in this table as put equal to the items they denote.

4. THEORETICAL CALCULATIONS

4.1. Regular Attendance

The parameters N, f, z and w shown also in Tables III and IV were used for the theoretical calculations of productivity for the spinning and winding machines respectively. If the variation with time of the number of machines stopping is obtained, starting with a value of zero when all machines are running, then the behaviour of man-machine system in a multi-machine assignment can be better investigated in many of its aspects by simple graphs. However, the fact that the time variable t is given in terms of the number of stopping machines n presented some difficulties. A computer programme was prepared to invert Equation (5) to get the number of stopping machines n as the function of time t. This was done by calculating the time t in succession for a set of values of n generated by the computer in ascending order and by comparing each value in turn with a given value of t also generated by the computer and increased by equal steps after each run.

The variation with time of the number of stopping machines is shown in Figures 1 and 2 for the spinning and winding machines respectively. It can be observed in both graphs that the number of machines stopping shows sudden jumps at single points above a succession of gradually increasing points. This is due to the mathematical structure of the function and does not reflect the true nature of the actual event. Therefore it can be concluded that the number of machines stopping at any time increases gradually until a limiting value is reached after which it remains constant.

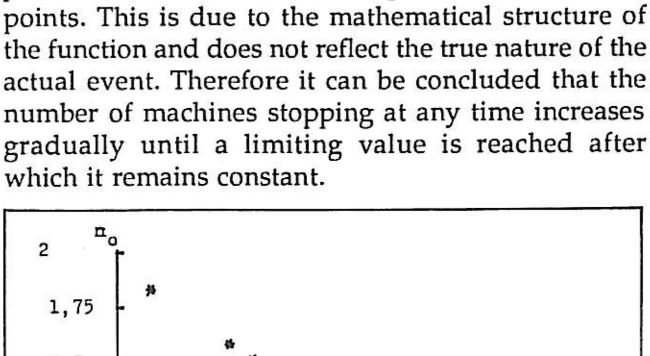

Fig. 1: The variation of the number of stopping machines with time in the Zinser spinning machine.

Şekil 1: Zinser iplik makinasında duran makina sayısının zamana göre değişimi

The programme also calculated the number of machines stopping at the steady state, n_o, by Equation (6), the cycle period and the efficiency. The results are shown in comparison with the experimental results in Table VII for both the spinning and winding experiments.

Table 7: Comparison of Theoretical and Experimental Results for Regular Attendance

Parameters	Spinning Exp.		Winding Exp.	
	Theory	Experiment	Theory	Experiment
Number of Stopping Machines	1,161	1,960	3,012	3,110
Cycle period (hour)	0,0228	0,0400	0,0330	0,0228
Efficiency (%)	99,71	99,51	87,95	87,56

4.2. Random Attendance

The machine interference or the fraction of the production time lost as a result of spontaneous machine stoppages when one operative tends several machines at random was given by the author previously [Başer, 1972-1] as

$$G=\frac{1}{2N}\left\{Np\left[(N-1)p-1\right]-(1-p)^{N}+1\right\} \quad (11)$$

where p is the work load of a single machine including walking time when the operative services it from an average distance. p is given as

$$p=\frac{t_d+t_e+t_y}{t_m+t_d+t_y} \quad (12)$$

where t_m is the automatic time, t_d is the total time spent by the operative to repair production breaks, t_e is the time spent for useful work when the machine is running and t_y is the time spent by walking. The machine efficiency can then be expressed as

$$R=\frac{t_m}{t_m+t_d+t_y+t_g} \quad (13)$$

where t_g is the time lost per machine due to interference given by

$$t_g=\frac{G}{1-G}\,(t_m+t_d+t_y) \quad (14)$$

By calculating the efficiency and machine interference from the parameters given in Table VI, a comparison between the theory and experiment may be made as shown in Tale VIII.

Table 8: Comparison of Theoretical and Experimental Results for Random Attendance

Parameters	Theory	Experiment
Efficiency (%)	93,98	93,72
Machine interference (%)	0,48	0,82

5. DISCUSSION OF THE RESULTS

5.1. Discussion of the Results of Regular Attendance Experiments

When the theoretical and experimental results shown in Table VII are compared, the agreement seems to be quite good both for the spinning and winding machines as far as the efficiency values are concerned. The agreement is better in the winding machine since the number of the stopping machines as determined both theoretically and experimentally are quite close. In the spining machine, however, the difference between the theory and experiment is somewhat large which can be seen as reflected in the efficiency figures when examined more carefully. It is 1-E that should be taken as the basis in comparing the theoretical and experimental efficiency values. They are 0.29 and 0.49 respectively for the spining machine, 12.05 and 12.44 respectively for the winding machine.

The agreement for the cycle period between theory and experiment is rather poor. The higher experimental value for the spinning machine is expected since the experimental number of the stopping machines is high too. But in the winding machine the experimental value is lower which may lead one to think that a different state of affairs may be the case and that a special theory may be needed for the bidirectional attendance. In the first cycle begining with the state when all machines are running the events will occur exactly in the same way as in unidirectional patrolling. But in the second cycle when the operative starts walking in the reverse direction, there will be fewer machines needing repair at the begining than towards the end of the cycle, assuming that the breakdowns in each machine occur at a constant rate. It may be that there will be very few breakdowns in the second cycle as compared with the first cycle depending on the breakdown rate and on the number of machines attended. Thus some of the cycle periods may be of very short duration as indeed was observed during the experiment on the winding machine attended bidirectionally. This may result in the cycle period never reaching a steady value and thus being lower than what the theory predicts.

As there was no prior experimental work reported on the subject, it was thought to be convenient to compare the theoretical values given by Bunday and Jackson (1975) in a table arrangement with those obtained by the present theory in the same way. Table IX shows the efficiency values for up to 28 machines for various values of the parameters λr and $N \lambda w$ given by Bunday and Jackson. Here λ is the breakdown rate, w is the walking time between machines, N is the number of machines assigned and r is the average repair time. A comparison between the values in Table IX with those given by Bunday and Jackson for unidirectional patrolling shows that the present theory gives a similar value for N = 2, $\lambda r = 0.05$ and $N\lambda w = 0$ (94.8 against 95.2 by Bunday and Jackson) but the values decrease at a greater rate, with the present theory, with increases in both λr and $N\lambda w$ than is the case in Bunday and Jackson's table. When a comparison is made with the table values given by Bunday and Jackson [1975] for bidirectional patrolling with constant walking time, a better agreement is obtained though their table start for N = 2 with a lower value which is 92.4

The advantage of the present theory is that it gives a simple formula, given by Equation (6), to calculate the number of stopping machines n_o, for any number of the assigned machines N. The efficiency can easily be calculated along with other important parameters such as the cycle period and the number of machines n_1, repaired in one cycle. This allows analytical examination of the problem to be made much easier.

Table 9: Efficiency Values for Unidirectional Attendance (%)

λr	$N\lambda w$/N	0.05	0.10	0.15	0.20	0.25
0.05	2	94.8	90.1	85.9	82.1	78.7
	4	94.2	89.2	84.7	80.7	77.2
	6	93.5	88.0	83.3	79.2	75.6
	8	92.6	86.7	81.8	77.5	73.8
	10	91.6	85.2	80.0	75.7	71.9
	12	90.0	83.0	78.0	74.0	70.0
	16	86.0	79.0	73.0	69.0	66.0
	20	80.0	73.0	68.0	64.0	61.0
	24	72.0	67.0	63.0	59.0	56.0
	28	65.0	60.0	57.0	54.0	52.0
0.10	2	94.2	89.2	84.7	80.7	77.2
	4	92.6	86.7	81.8	77.5	73.8
	5	92.0	85.0	80.0	76.0	72.0
	6	90.2	83.3	78.0	73.6	69.9
	8	86.1	78.7	73.4	69.1	65.5
	10	80.0	73.0	68.1	64.2	61.0
	12	72.0	67.0	63.0	59.0	56.0
	16	58.0	55.0	52.0	50.0	48.0
	20	48.0	46.0	44.0	43.0	41.0
	24	40.0	39.0	38.0	37.0	36.0
	28	35.0	34.0	33.0	32.0	32.0
0.15	2	93.5	88.0	83.3	79.2	75.6
	4	90.2	83.3	78.0	73.6	69.9
	6	83.3	76.0	70.8	66.7	63.3
	8	72.0	67.0	63.0	59.0	56.0
	10	61.0	58.0	55.0	52.0	50.0
	12	52.0	50.0	48.0	46.0	44.0
	14	46.0	44.0	42.0	41.0	40.0
	16	40.0	39.0	38.0	37.0	36.0
0.20	4	86.1	78.7	73.4	69.1	65.5
	6	72.0	67.0	63.0	59.0	56.0
	8	58.0	55.0	52.0	50.0	48.0
	10	48.0	46.0	44.0	43.0	41.0
	12	40.0	39.0	38.0	37.0	36.0
0.25	2	91.6	85.2	80.0	75.7	71.9
	4	80.0	73.0	68.1	64.2	61.0
	6	61.0	58.0	55.0	52.0	50.0
	8	48.0	46.0	44.0	43.0	41.0
	10	39.0	38.0	37.0	36.0	35.0

5.2. Discussion of the Results of Random Attendance Experiment

From a comparison of the experimental and theoretical values of machine efficiency shown in Table VIII, it can be said that the agreement between theory and practice is very good. Nevertheless, the theory gives 0.48 % machine interference as against 0.82 % determined experimentally. It may be that the operatives did some useful work when the machine was runing, which may have contributed to the interference by increasing the value of p given in Equation (12) although they were given the instruction not to do. However, to be more precise it may be stated that more experimental work is necessary, perhaps by repeating the same experiment for varying numbers of machine assigned to the operative, to fully verify the theory.

The real advantage of the method of calculating machine interference by Equation (11) is that it is a direct calculation not needing any iteration as in Jones' (1965) method. Jones gives the mchine interference i as,

$$i = A - \frac{1-(1-A)^n}{n} \quad \text{......} \quad (15)$$

where n is the number of machines assigned to the operative and A is given by

$$A = S\,(1 - i) + i \quad \text{......} \quad (16)$$

where S is the work load. Here i is a function of A which is the probablility that a machine needs attendance at any time, which is itself the function of i. This is why iteration is necessary to find the machine interference i. A single formula given by Equation (11) enables us to put the time loss due to interference in the general form of the formula for machine efficiency for random attendance as in Equation (13) which is suitable for analytical evaluations.

The problem of random attendance is very important because even if the machines are attended regularly, there are ancillary works to be done such as doffing in many machines or setting the warp on the looms. Since these operations are carried out by special teams of operatives, they are of kind of random services carried out when need arises. By the method explained here the effect on machine efficiency of such ancillary work can easily be taken into acccunt in efficiency calculations.

One difficulty remains unsolved, however, and that is the effect on machine efficiency of the surplus work load when the total work load of an operative tending N machines is greater than unity or 100 %. Then the formula given in Equation (13) will not hold since the operative will be short of time to achive the efficiency value given by this formula. If the work load of the operative for N machine is Z, then the surplus work load per machine, K, will be

$$K = \frac{Z-1}{N} \quad \text{......} \quad (17)$$

and this will give rise to a loss of production time t_k given by

$$t_k = \frac{K}{1-K}\,(t_m + t_d + t_y + t_g) \quad \text{......} \quad (18)$$

The efficiency formula in Equation (13) will then include t_k also in the denominator as an additional time element.

6. CONCLUSIONS

A mathematical approach made in this paper to calculate the efficiency of a set of machines attended by one operative provides formulae for both regular and random attendance, which allow direct analytical investigations.

The verification of the two theories by experiments was achieved to some extent in so far as the agreement obtained with the efficiency values. The calculated cycle periods in regular attendance and machine interference in random attendance did not agree well with the experimental results. Therefore, for a full varification of the theories more experimental work is necessary.

ACKNOWLEDGEMENT

The author wishes to express his gratitude to Aytekin Kabu who carried out the time studies as planned.

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