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On the Balance of Skill and Operation*

(1st Report, On the Business Management Using the Modified Control Chart of the Flicker Value)

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This paper deals with the problem of the business management of workers using the control chart of flicker value. We define the range of flicker value for a day or two consecutive days. This measure is to reduce the personal difference of flicker value. The control chart of the quality control is modified to be suitable for the business management. This method is applied to the control of bus drivers in working hours. Then it is made clear that the range of flicker value of worker decreases as worker's years of experience increase and factors which disturb the controlled condition can be found from this chart.

It is possible to carry out the business management numerically by this method.

1. Introduction

The working ability of workers, the substance of work and the environment of work should be investigated in detail in order to make appropriate business management. In mental work, one of the influences of the working conditions on workers is presented as the phenomenon of decrement or increment of the flicker's discriminant ability of the eye. This ability is measured by the flicker value tester^{(1)~(3)}.

The authors^{(4) (5) (10)} attempted to control workers by the flicker value in working hours using the control chart method of the manufacturing process. But it is inadequate to use this control chart without modification. Further, as it is recognized that there are personal differences among flicker values of individuals, workers can not be controlled by this measure. For example, M. Ōshima⁽⁷⁾ defined the ratio of the decrement of flicker value in a day or in a week. But it is inconvenient to use this ratio for the control of workers while working. Therefore the authors define the range of flicker value for a day or two consecutive days. Then the worker is controlled by the range using the modified method. Factors which disturb the controlled condition are taken up from the control chart and these make

clear the case in which fatigue or a decrement of faculty occurs in workers. The tendency of flicker value is examined for the purpose of using the control chart. It is possible to carry out the business management numerically using these results.

2. Subjects and investigated method

Subjects are bus drivers who should be controlled by the business and labor management⁽⁹⁾. The investigation is done as follows. In the first place, the flicker tester is set at one business office operating 21 regular bus routes. In this office, almost all drivers have the experience of less than six years. Thirteen subjects are selected from among them and investigated over about 3/2 month. Flicker values are measured at the commencement hour of work, at the time when the subject comes back to report to the office during the working hours and at the closing hour. At the commencement hour of work, they are measured after roll call and the working check (20 minutes), and after putting the bus into the shed at the closing hour. This investigation was carried out from the latter part of January to the beginning of March in 1967.

When experience exceeds six years, the duty of drivers changes from regular routes to sightseeing tours. Drivers are assigned individually to one bus. So in the case of sightseeing tour, the flicker tester is set in the bus, then flicker values of the driver of this bus are measured at any given time. The second step of the investigation was carried out from the middle part of May to the latter part of October. In this period, 9 persons' flicker values

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are measured. Subjects are in the age group of 27 to 52 years in both investigations, all being male.

The flicker tester of sector type is used to measure the flicker value. In the measurement, the sector rotates fast at first and gradually slows down and when the eye recognizes the flicker of light, it is measured by c/sec. Flicker values are measured four times at a time and the minimum and maximum values are rejected and the average of the others is regarded as a observed value at that time. It is impossible to carry out the mass measurement at the same time because of the difference in the duty hours of individuals. So the hours ranges in which most of measurements are included are set up as follows.

the first	(at the commencement hour)
	5 : 30—8 : 30
the second	(at the lunch period)
	11 : 30—14 : 00
the third	(at the closing hour)
	17 : 00—21 : 00

Subjects are classified into four groups by years of experience for the following reasons.

Group	Years of experience (X)	Number of subjects	Reason
a	$0 \leq X < 3$	8	shows high accident rate
b	$3 \leq X < 6$	5	before the change of duty
c	$6 \leq X < 15$	6	learns the work and shows stable response
d	$15 \leq X$	3	considers the influence of ages.

3. Method and analysis

As the calculation of the ratio of decrement of flicker value in a day or in a week contains the arithmetical division, it is inconvenient to control workers while working. Therefore the range value and the deviation can more easily be defined from the flicker value.

a_{ijk} : the flicker value of subject i , j th day and k th time.

$i=1, 2, \dots, m, j=1, 2, \dots, r, k=1, 2, \dots, n$

R_{ij} : the range of j th day of subject i in a day.

$$R_{ij} = \max_k a_{ijk} - \min_k a_{ijk}$$

$i=1, 2, \dots, m', j=1, 2, \dots, r'$

R_{ij}' : the range of subject i between the last observed value of j th day and the first observed value of $j+h$ th day (in short, the range between days).

$$R_{ij}' = |a_{ij+h1} - a_{ijn}|$$

$i=1, 2, \dots, m'', j=1, 2, \dots, r''$

$\bar{R}_i, \bar{R}_i'$: subject i 's mean value of the range in a day and between days.

$$\bar{R}_i = \sum_{j=1}^{r'} R_{ij} / r', \quad \bar{R}_i' = \sum_{j=1}^{r''} R_{ij}' / r''$$

$\bar{R}, \bar{R}'$: mean values of the range in the designated group.

$$\bar{R} = \sum_{i=1}^{m'} \bar{R}_i / m' = \sum_i \sum_j R_{ij} / m' r', \quad \bar{R}' = \sum_{i=1}^{m''} \bar{R}_i' / m''$$

The calculating method of the control chart of the range in a day or between days is same. Therefore the control chart method of the range in a day is described in detail.

3.1 Control chart of the range

Coefficients used in the quality control are that of level 1%. When these coefficients are used in the business management, the degree of confidence is 99%. So almost all data are accepted. Then coefficients of level 5% (in the quality control, say, the warning limit) are used in this analysis. In general, the control chart of the range is given as follows.

$\bar{R} A_{1\alpha}(n) \leq \tilde{R} \leq \bar{R} A_{2\alpha}(n)$: the control chart of the range.

$\tilde{R}$: the population range

$A_{1\alpha}(n), A_{2\alpha}(n)$: coefficients are obtained by the given n and α from the table⁽⁶⁾.

Further $A_{1\alpha}(n) = 1 - 2d_3/d_2, A_{2\alpha}(n) = 1 + 2d_3/d_2$. Then these are calculated by the table⁽⁶⁾ of d_2 and d_3 . $\bar{R} A_{1\alpha}(n)$ denotes the lower control limit (in short, L.C.L.) and $\bar{R} A_{2\alpha}(n)$ the upper control limit (U.C.L.).

When $n \leq 6$, then $A_{1\alpha}(n)$ is not considered and when $n > 6$, then $A_{1\alpha}(n) > 0$. In business management, when the range is equal to zero, (i.e. all observed values are equal to each other in a day or two consecutive days) there is no reason in the labor science for rejecting these data. Therefore the control chart of the range which has level 5% and L.C.L.=0 is made as follows. The probability density function of the range is given by

$$f(R) = \int_{-\infty}^{\infty} n(n-1) \left\{ \int_{x_1}^{x_1+R} \phi(x) dx \right\}^{n-2} \times \phi(x_1) \phi(x_1+R) dx_1 \dots \dots \dots (1)$$

$R \geq 0$ and x_1 is the minimum of data of size n which is sampled from the population having $\phi(x)$.

The population mean and variance of R are

$$E(R) = d_2 \sigma, \quad V(R) = d_3^2 \sigma^2 \dots \dots \dots (2)$$

σ^2 is the variance of $\phi(x)$.

In the equation (1), $\omega = R/\sigma$, then

$$P_r \{0 \leq \omega \leq K\} = \int_0^K f(\omega) d\omega = \alpha \dots \dots \dots (3)$$

In the Eq. (3), when α is given, K is obtained from the table⁽⁶⁾. From the equation in braces of (3),

$$0 \leq R \leq \sigma K \dots \dots \dots (4)$$

From the Eq. (2), R/d_2 is the unbiased estimator of σ and $\bar{R}$ is the mean value of the range of sample, then

$$E(\bar{R}) = d_2 \sigma \dots \dots \dots (5)$$

$\bar{R}/d_2$ is the unbiased estimator of σ .

Then from the Eq. (4), (5),

$$0 \leq R \leq \bar{R}K/d_2 \dots \dots \dots (6)$$

The relation of (6) gives the modified control chart of the range for business management. K and d_2 are determined for given level α and sample size n . Therefore Table 1 shows the value of K/d_2 for $n=2 \sim 15$ and $\alpha=0.1 \sim 0.01$. In this control chart, L.C.L.=0 and U.C.L.= $\bar{R}K/d_2$. The range of flicker value can be controlled by this method.

As the flicker value of individuals shows personal differences, it is disadvantageous to control the individual by $\bar{x}$ -control chart which calculates by the mean value of a group. Therefore it is appropriate to control by the individual data. As the minimum and maximum in data are used to calculate the range, it is reasonable to use the minimum, maximum and modified R control chart instead of $\bar{x}$ -modified R control chart. So U.C.L. and L.C.L. at level 5% of the minimum and maximum of flicker value are calculated as follows. The detailed calculating process is omitted. $\bar{S}$ and $\bar{L}$ denote average values of the minimum and maximum in each day.

Then

$$\text{U.C.L.} = (\bar{S} + \bar{L})/2 + (1/2 + 2e_3/d_2)(\bar{L} - \bar{S})$$

$$\text{L.C.L.} = (\bar{S} + \bar{L})/2 - (1/2 + 2e_3/d_2)(\bar{L} - \bar{S})$$

e_3 and d_2 are obtained from the table⁽⁸⁾ for given sample size n . Table 2 shows the coefficient ($A_{10} = 1/2 + 2e_3/d_2$) for $n=2 \sim 10$ and $\alpha=0.05$.

3.2 Ratio test using the sign of deviation of flicker value

The previous method does not investigate the tendency of flicker value in the working time. Then the deviation of flicker value is defined as follows in order to examine the tendency.

A_{ijkpq} : the deviation of subject i between p th

Table 1 Coefficient of modified R control chart

n	α	K/d_2			
		0.1	0.05	0.025	0.01
2		2.07	2.46	2.81	3.23
3		1.71	1.96	2.17	2.43
4		1.57	1.76	1.93	2.14
5		1.50	1.66	1.81	1.98
6		1.44	1.59	1.72	1.88
7		1.41	1.54	1.66	1.80
8		1.38	1.51	1.62	1.75
9		1.36	1.48	1.58	1.71
10		1.34	1.45	1.56	1.68
11		1.33	1.43	1.53	1.65
12		1.32	1.42	1.51	1.62
13		1.30	1.41	1.50	1.60
14		1.29	1.39	1.48	1.59
15		1.29	1.38	1.47	1.57

observed value of $j+k$ th day and q th
observed value of j th day

$$= a_{ij+kp} - a_{ijq}$$

$$j=1, 2, \dots, m_{kpq}, \quad p, q=1, 2, \dots, r, \quad k=1, 2$$

The tendency is examined by χ^2 -test using the sign of A_{ijkpq} . For the given k, p and q , we put m_{ijkpq} = frequency $\{A_{ijkpq} < 0\}$ with respect to j . The hypothesis is $P_{ijkpq} = 1/2$. That is, the frequency of p th observed value of $j+k$ th day being higher than q th observed value of j th day is equal to that of the inverse relation. Under this hypothesis, the test formula is given as follows.

$$\chi_0^2 = (2m_{ijkpq} - m_{kpg})^2 / m_{kpg}$$

Then $\chi_0^2 \geq \chi_{\alpha}^2(1)$, so this hypothesis is rejected and the tendency of observed values of one side being higher than others is recognized at level $100\alpha\%$. $\chi_0^2 \leq \chi_{\alpha}^2(1)$, so the hypothesis is accepted and it is recognized that there is not any evident tendency between the observed values.

4. Result

4.1 Control chart of the range in a day

The range is calculated from three observed values in a day. Then n is equal to three. The propriety of the grouping of subjects is examined by the variance ratio test before the calculation of the control chart. Table 3 shows the sample variance in each group and the result of variance ratio. The sample variance decreases as subject's years of experience increase, but when experience is longer than 15 years, the sample variance again increases. The variance ratio between a and c is 3.58 and that between b and c is 2.15. The former is greater than $F_{0.05}(95, 40) = 1.60$ and the latter is greater than $F_{0.05}(63, 40) = 1.60$, where, $F_{\alpha}(n_1, n_2)$ is the value of Fisher's distribution of d.f. (n_1, n_2) at level $\alpha \times 100\%$. Then there is a significant difference at level 5% on one sided test between c and a or b . There is not a significant difference between c and d . Then subjects are classified into two groups, one being a and b (writes, $a+b$) and the other c and d ($c+d$). So the variance ratio is 2.54 and $F_{0.05}(159, 63) = 1.47$. Therefore there is significance at level 5% between $a+b$ and $c+d$. Further the

Table 2 2σ coefficient of min.-max. control chart

n	A_{10}
2	1.965
3	1.384
4	1.181
5	1.075
6	1.009
7	0.963
8	0.929
9	0.903
10	0.881

variance ratio between d and a is 2.15 and $F_{0.05}(63, 22)$ is 1.89. Then there is significance at level 5% between d and a . b , c and d are lumped in one group which will be called $b+c+d$. Then there is a significant difference at level 5% between a and $b+c+d$. It is made clear that the range of flicker value in a day decreases as years of experience increase till 15 years of experience. And the propriety of grouping by the years of experience and the substance of the labor is shown by the variance ratio test. $\odot$

Using these results, one and two rows in Table 3 show the mean value and the upper control limit of the range in a day in each group. These values show the same tendency as the sample variance. Subjects in each group are controlled by its own control limit. Subjects are classified into two groups ($a+b$, $c+d$) by the result of variance ratio test. The control limit of $a+b$ group is 4.62 c/sec and that of the other group 3.25 c/sec. Then b group is controlled by U.C.L. of $a+b$. But the range of b is significantly smaller than that of a , then U.C.L. of $a+b$ is weak for b . When U.C.L.=3.70 c/sec of $b+c+d$ is used, subjects are in the most strongly controlled condition. And further in a strongly controlled condition, it is adequate to use U.C.L.=4.23 c/sec. It is adequate to use control limits (4.62 c/sec, 3.25 c/sec), when subjects are classified into two groups by years of experience. Figure 1 and Fig. 2 show the $\bar{x}$ -modified R control chart of flicker value in a day of one subject in a and min.-max. and modified R control chart of one subject in c .

Fig. 1 $\bar{x}$ -modified R control chart of range of one subject in a in a day

Fig. 2 Min.-max. and modified R control chart of range of one subject in c in a day

Table 3 Range in a day in each group

Group	a	b	c	d	$a+b$	$c+d$	$b+c+d$	Total
Mean value	2.52 c/sec	2.13	1.62	1.74	2.36	1.66	1.89	2.16
Upper control limit	4.93 c/sec	4.15	3.17	3.40	4.62	3.25	3.70	4.23
Sample variance	3.305	1.984	0.922	1.474	2.799	1.104	1.583	2.407
Degree of freedom	95	63	40	22	159	63	127	
Variance ratio	u_c^2/u_a^2	2.15*	1.00	1.60				
	u_c^2/u_b^2	2.24*	1.35	1.00				
	u_c^2/u_d^2	1.67*	1.00	2.15*				
	u_{a+b}^2/u_{c+d}^2				2.54*	1.00		
	u_a^2/u_{b+c+d}^2	2.26*					1.00	

* Rejects at level 5%

Factors which disturb the controlled condition are made clear by the investigation of cases in which the range oversteps a given control limit. The range oversteps the limit 38 times in all subjects in the most strongly controlled condition i.e. under use of U.C.L.=3.70 c/sec. It is made clear that the weather (rainy day or cloudy day) during the working hours, the working of special routes (2 routes) and the day after holiday in all day or only in the afternoon influence the range considerably. Flicker values lower extremely at the closing hour, when the working day is rainy or cloudy and it lowers extremely at the commencement hour, if the previous day was a holiday. Therefore subjects are fatigued in the afternoon of rainy or cloudy day and their faculties lower extremely in the forenoon after holidays. Then the supervisor should take scrupulous care of the subject from the business management point of view whenever these factors exist.

This control chart of the range in a day has a weak point, that is, it can not be controlled directly during working hours because the range is calculated from three observed values in a day. Therefore the control chart of the range of two consecutive days should be investigated.

4.2 Control chart of the range of two consecutive days

The range of two consecutive days is the absolute value of the observed value at the closing hour minus that at the commencement of next day. Then n is equal to two. By using this control chart

of the range, subjects can be checked before work. Accordingly this control chart is more useful than the previous chart.

Table 4 shows the sample variance and the result of variance ratio test. The longer the experience is, the more the sample variance decreases. There are significant differences between a and the others. Therefore the range becomes stable after about three years of experience and thereafter does not change markedly. In d , the sample variance takes the minimum. This phenomenon shows that subjects in d are accustomed to working for long time and this is not made clear from the analysis of the range in a day. One and two rows in Table 4 show the mean value and U.C.L. The limit line of a is higher than the others and these are nearly equal in b , c and d . U.C.L. in a is 4.37 c/sec and that of $b+c+d$ 2.90 c/sec. When subjects are controlled by two control limits, it is adequate to use these limits. Further as U.C.L.=2.90 c/sec of $b+c+d$ is used, subjects are in the most strongly controlled condition. Then many factors which disturb the controlled condition can be easily picked up. Figure 3 shows the min.-max. and modified R control chart of two consecutive days of one subject in a .

The factor of weather (rainy or cloudy) has strong influence on the range of two consecutive days, too. And the routes influencing the range increase from two to four routes. The day after holiday or after a day when subjects went to the office but worked at the other section also is a

Fig. 3 Min.-max. and modified R control chart of the range of one subject in a in two consecutive days

factor which disturbs the controlled condition. Therefore it is made clear that the weather, special routes and the working condition of the previous day have strong influence on the range in a day or in two consecutive days.

By these results, it is made clear that the range of two consecutive days becomes stable from about three years experience and the degree of stability increases as years of experience increase.

4.3 Flicker variation in the forenoon, afternoon and two consecutive days

If the tendency of flicker value in a day or two consecutive days is investigated, once the flicker value is measured at a certain time, it is possible to estimate the flicker value at a given time afterwards. Then subjects can be controlled more precisely using the control chart and the tendency of flicker value.

Notations (up or down) are used to show the tendency, when there is a significant difference by χ^2 -test; "up" shows the case when the frequency of $\{A_{ijkpq} < 0\}$ is too small, then the hypothesis is rejected; and "down" is the case when the frequency of $\{A_{ijkpq} < 0\}$ is too large, then the hypothesis is rejected. At the sign up, the observed flicker value of the lunch period is higher than the commencement hour in the forenoon, that of the closing hour is higher than the lunch period in the afternoon and the commencement hour in the next day is higher than the closing hour in the previous day in two consecutive days. Sign down shows the inverse relation to sign up.

Table 5 shows the result of each group in the forenoon, afternoon and two consecutive days. As

Table 5 Tendency of flicker value in each group

Group	Forenoon		Afternoon		Two consecutive days	
	χ^2	sign	χ^2	sign	χ^2	sign
a	23.40*	up	0.64		0.01	
b	22.75*	up	0.13		0.22	
c	12.07*	up	1.37		0.00	
d	0.71		11.65*	up	4.83*	up

* Rejects at level 5%

Table 4 Range of two consecutive days in each group

Group	a	b	c	d	$a+b$	$c+d$	$b+c+d$	Total
Mean value	1.93 c/sec	1.17	1.24	1.14	1.61	1.19	1.18	1.53
Upper control limit	4.73 c/sec	2.87	3.04	2.81	3.96	2.93	2.90	3.75
Sample variance	3.693	0.933	0.954	0.773	2.687	0.863	0.891	2.041
Degree of freedom	102	71	41	34	174	76	148	
Variance ratio	u_1^2/u_d^2	4.78*	1.21	1.23	1.00			
	u_1^2/u_b^2	3.96*	1.00	1.02	1.21			
	u_c^2/u_d^2	3.87*	1.02	1.00	1.23			
	u^2_{a+b}/u^2_{c+d}							
	u^2_a/u^2_{b+c+d}	3.28*				1.00		

* Rejects at level 5%

the hypothesis is rejected in a , b and c , the flicker value increases from the commencement of work to the lunch period. And this degree lowers as subject's years of experience increase in the same way as in the range of two consecutive days. This shows that subjects have become skillful through many years of working. As the hypothesis is accepted in d , flicker values do not show any specific tendency in the forenoon. In the afternoon, there is not a significant difference in a , b and c at level 5% but in d , there is a significant difference. That is, the flicker value at the closing hour is higher than that at the lunch period in d . There is a significant difference in d in two consecutive days. Then the flicker value at the commencement of the next day is higher than that at the closing hour of the previous day.

From these results, it can be said that subjects in c and d show stable response to the work. And this result is the same as that of the range in a day and in two consecutive days. Subjects who show a decreasing tendency of flicker value should be given some advice.

5. Conclusions

Various ranges and deviations of flicker value are defined. Subjects are classified into four groups according to years of experience. Control limits of ranges are calculated by the modified control chart method in each group. And the tendency of flicker value is examined by χ^2 -test from the sign of deviations. Then the following results are obtained.

(1) The range in a day decreases in the order of a , b and c , and that of d is slightly larger than that of c . From the result of variance ratio test, it is made clear that subjects are classified into two groups, one being a and b and the other c and d . Then subjects are controlled by limits (4.62 c/sec and 3.25 c/sec) in each group. But when U.C.L. = 3.70 c/sec of $b+c+d$ is used, subjects are in the most strongly controlled condition. And further in strongly controlled condition, that (4.23 c/sec) of all subjects is used. The weather (rainy or cloudy) during the working hours, the working of special routes and the day after holiday have considerable influence on the range in a day.

(2) The range of two consecutive days in a is higher than those of b , c and d . Those of b , c and d are about equal to each other, but it is the lowest in d . Therefore when the control limit (2.90 c/sec) of b , c and d is used, all subjects are in the most strongly controlled condition. Factors which disturb the controlled condition of the range of two consecutive days are almost the same as those in a day.

(3) Flicker values of a , b and c increase from the commencement hour of work to the lunch period in the forenoon. Therefore the faculty of subjects in these groups falls at the commencement, so from the business management point of view advice should be given to these subjects. In the afternoon and two consecutive days, there is a significant difference only in d . That is, the flicker value in d increases from the lunch period in the previous day to the commencement of work in the next day.

From the results of the range in a day and two consecutive days and the tendency of flicker value, it is made clear that subjects in c and d are accustomed to the work and have learned the work well enough. So these subjects are fit for this work. The method in which the range of flicker value is controlled by the modified control chart is investigated to make the numerical business management possible. Then the propriety of this method is made clear from the result of a bus driver's control chart of the range in a day or two consecutive days.

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