SOME INVESTIGATIONS ON PRODUCTIVITY CONTROL IN HANDMADE PAPER INDUSTRY

by

A. V. Venkatesam,* A. Gopalakrishnan, A. Rahman,*
Regional Research Laboratory, Hyderabad

ABSTRACT

The paper gives some results of the investigations on productivity control in handmade paper Industry. The advantages of splitting up the entire operation into several sub-operations for controlling the productivity have been specially indicated.

Introduction

The hand-made paper industry once flourishing and wide-spread is able to continue now only through subsidy. In the wake of mill-made paper it is often forgotten that certain types of paper can be made by hand only. That there is a demand is evident from imports and that these types can be made in India is also clear, what remains to be achieved is their economic manufacture. With this end in view twofold investigations were initiated by Central Laboratories for Scientific and Industrial Research, Hyderabad, now constituted into Regional Research Laboratory under C.S.I.R. The first were aimed at technical improvement of the processes including modifications of machinery, and the second at improving the efficiency of production. In this paper only the latter are described†. The main idea behind the study was to analyse production from the point of efficiency of labour and production within a unit and in relation to other units and to avoid wastage.

Process of Manufacture

The process of making hand-made paper consists of the following stages.

(*i*) Sorting the rags of required colour from the tailor cuttings which forms the raw material for paper making in the hand-made paper section of the laboratory.

(*ii*) Cutting the rags into small bits before it is sent for pulping.

(*iii*) Preparation of pulp.

(*iv*) Lifting of paper of the required quality and size (the quality of the paper depends on the distribution of pulp per unit area as also the type of rags used).

(*v*) Drying the lifted papers

(*vi*) Sorting good papers out of the dried lot for further operations (This is done by visual inspection)

(*vii*) Sizing of the paper with the use of proper adhesives and chemicals

(*viii*) Drying the paper which has been sized

(*ix*) Sorting of good papers out of the lot obtained in the previous operation for further operations (by visual inspection)

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*Present address: Central Building Research Instt., Roorkee.

† The work is incomplete in a way as some of the modifications suggested were not tried and their efficiency evaluated.

(*x*) Calendering of the paper

(*xi*) Sorting good paper out of the papers calendered (by visual inspection)

(*xii*) Cutting the paper to required size.

These were studied step by step and the preliminary study revealed the importance of the following stages from the point of production :

(*i*) Lifting of paper

(*ii*) Sorting of paper at various stages of production.

Sorting of the paper at various stages; after drying, before sizing and calendering could result in considerable economy. The lack of it could result in very high rejection at the end and it was 40% when the study was initiated. A sequential sampling procedure was, therefore, suggested to bring down the number of rejects.

The most important step in the production of hand-made paper is lifting. This was studied in detail technically as well as in relation to the productivity of the worker.

The lifting of paper was done on a *Vat*, designed and fabricated at the Laboratory. The operation consists of the following independent and disjoint sub-operations:

(1) taking the pulp into the mug and pouring it into the Vat
(2) spreading the pulp on the sieve
(3) drawing the tank and releasing the clamps
(4) handing over the sieve with the paper to the Coucher and taking and fixing an alternate sieve to the clamps
(5) raising the tank to the original position.

Advantages of the breakdown of an operation into disjoint and mutually independent sub-operations.

(*i*) Breakdown introduces constraints which probably go to increase the efficiency of the estimate.

(*ii*) Breakdown facilitates the establishment of limits for running control charts for the sub-operations, which will be of immense value to localise the defects in the sub-operations and take effective action when the control chart for the daily productivity and therefore the control chart of the entire operation goes out of control.

(*iii*) Estimates of the parameters of the sub-operations might suggest useful modifications in the sub-operation so that the sub-operation is expedited and the entire operation performed in quicker time.

Description of the investigation

The operation of lifting of paper comprises five independent and disjoint sub-operations mentioned earlier. Observations of the time (in seconds) taken for performance of each of the sub-operations were recorded for the manufacture of paper of a known type. The recording of observations was spread over twenty-five working days and four random readings of each of the five sub-operations were collected. The average of four readings (sub-group) for each day and for each sub-operation has been given in Table. I.

TABLE I

Distributions of the time in seconds for single performance of the sub-operations

(Mean of 4 observations each)

Sub-group No.	Sub-operations				
	No. 1	No. 2	No. 3	No. 4	No. 5
1	11·8	26·25	91·63	11·65	19·88
2	13·4	41·48	86·75	14·65	29·55
3	13·95	36·15	82·65	13·00	25·30
4	8·75	18·38	24·70	8·25	8·53
5	9·2	13·85	19·70	8·10	10·35
6	9·75	20·95	54·65	7·85	12·65
7	8·85	20·85	57·25	10·25	13·90
8	8·65	16·85	67·75	11·55	13·20
9	14·1	33·80	75·30	16·40	11·65
10	9·95	32·70	85·40	11·55	9·15
11	8·43	32·05	74·83	12·25	10·60
12	7·70	32·95	73·50	9·85	11·65
13	12·45	36·50	69·60	10·75	14·70
14	11·10	24·10	83·45	12·30	15·30
15	12·83	25·73	59·85	10·60	13·70
16	14·15	31·40	95·05	10·70	16·15
17	9·85	30·75	69·20	12·30	12·45
18	14·75	28·50	67·80	9·75	10·40
19	7·60	24·55	53·90	13·45	8·40
20	14·30	15·90	40·28	10·18	15·48
21	9·45	13·80	27·45	14·55	13·25
22	8·25	18·63	36·35	11·40	13·12
23	8·10	14·00	25·20	9·35	10·75
24	10·40	16·20	23·55	12·15	11·35
25	8·35	17·80	22·10	8·30	10·50

General Remarks based on Observations during experimental investigation

Visual observations revealed that in the existing system of lifting the paper, lifter and the coucher are called in to help in the pressing and since much time is spent on pressing operation, there is inordinate time-lag between the presses which affects the daily production. In order to systematize the work it is recommended that the job of pressing be exclusively assigned to certain workers and to introduce hydraulic press to make the operation of pressing less exacting. This modification will enable the workers lifting the paper to lift a larger number of papers. For example assigning half hour rest between each press and a break of half hour for lunch, the workers can be expected to lift 150 papers on a daily average, should each press consist of 50 papers and they are expected to lift papers for at least 3 presses daily. However it was noted that the average productivity per day never exceeded 120 papers. It was expected that the implementation of the suggestion would increase daily productivity by a minimum of 30 papers and step up monthly production by approximately 1½ reams, and the annual production by 18 reams. Thus allowing as much as 10% of the production for overall defects at different stages, the addition to the quantity of saleable paper will be 16·2 reams which at Rs. 500 per ream will cost Rs. 9,072 so that even if the implementation of the suggestion meant an addition of 3 more workers on an average wage of Rs. 1/8/- per day (existing wage rate) on the assumption that a year consisted of 300 working days, the net profit will be Rs. 7,722 annually less the cost of raw materials, chemicals, etc. Besides, it was felt that once the number of presses to be carried out in a day and the number of papers to be lifted in each press is decided upon, effective measures should be taken to strictly observe the directions. It was felt that it could be done only by a systematic and regular supervision of each press, to be carried out for 10 to 15 minutes daily. This sort of supervision will introduce a system and order in the lifting operation and will step up production and give homogenous product. It was, therefore, suggested that a full-time supervisor be appointed in order to exact *minimum specified workloads.*

Since 100% inspection was done at the three stages and the over-all defects in the papers calendered was attributable to the lack of control of defects at the stages mentioned earlier it was suggested that a sequential sampling procedure for inspection of the lot be followed, subject to certain ceiling of defects at those stages.

Statistical Analysis of the data

Assuming the variable X, the time taken for the entire operation of lifting a paper once and variables $X_1, X_2 \ldots\ldots X_5$, the times taken for sub-operation to be normally distributed with means μ^*, μ_i^*, $(i=1, 2 \ldots\ldots 5)$ and standard deviations σ^*, σ_i^* $(i = 1, 2, \ldots\ldots 5)$ respectively it is possible to estimate the parameters of the distribution of sub-operations of the entire operation.

The confidence interval for the means μi based on sample size N for the sub-operations can be written as

$$\mu_i - T\alpha \frac{\sigma^{i*}}{\sqrt{N}}, \mu_i + T\alpha \frac{\sigma_i^*}{\sqrt{N}} \quad (i=1, 2 \ldots\ldots 5)$$

where $T\alpha$ denotes the standard normal variate at the preassigned value α o level of significance.

If X the time variable for the entire operation is supposed to be compounded of x_i's the time variables for the five mutually independent and disjoint sub-operations then

$$E(x) = \sum_i \mu^*_i = \mu^* \quad (i = 1, 2, \ldots\ldots\ldots 5)$$

$$V(x) = \sum_i \sigma_i^{*2} = \sigma^{*2} \quad (i = 1, 2, \ldots\ldots\ldots 5)$$

Therefore, the confidence interval for the means of sample size N for the variable X is given by

$$\mu^* - T_\alpha \frac{\sigma^*}{\sqrt{N}} ; \mu^* + T\alpha \frac{\sigma^*}{\sqrt{N}}$$

where $\mu^* = \sum_i \mu^*_i \quad (i = 1, 2, \ldots\ldots\ldots 5)$

$$\sigma^{*2} = \sum_i \sigma^{*2}_i \quad (i = 1, 2, \ldots\ldots\ldots 5)$$

The estimates of the parameters of the distribution of the time in seconds for single performance of each of the sub-operations of the entire operation as also 95 per cent confidence intervals for sub-group means are given in Table 2.

TABLE II

Estimates of the parameters for the distribution of the variable —the time taken for single performance of the entire operation and the sub-operations

	Sub-operation					Entire operation of lifting
	No. 1	No. 2	No. 3	No. 4	No. 5	
Population Mean ..	10·65	24·96	58·48	11·25	13·65	118·99
Population standard deviation.	3·237	8·641	25·690	2·597	5·443	27·96
Coefficient of variation	30·39	34·62	43·93	23·08	39·88	23·50
95% Confidence interval for sample of size n	$10{\cdot}65 \pm T_{\cdot 05} \times \frac{3{\cdot}237}{\sqrt{N}}$	$24{\cdot}96 \pm T_{\cdot 05} \times \frac{8{\cdot}641}{\sqrt{N}}$	$58{\cdot}48 \pm T_{\cdot 05} \times \frac{25{\cdot}69}{\sqrt{N}}$	$11{\cdot}25 \pm T_{\cdot 05} \times \frac{2{\cdot}597}{\sqrt{N}}$	$13{\cdot}65 \pm T_{\cdot 05} \times \frac{5{\cdot}443}{\sqrt{N}}$	$118{\cdot}99 \pm T_{.05} \times \frac{27{\cdot}96}{\sqrt{N}}$

Where $T_{\cdot 05}$ is the standard normal variate at 5% level of significance.

NOTE—Instead of the factor $\frac{T_{\cdot 05}}{\sqrt{N}}$ calculated values of the factor for known sample sizes upto 25 from standard tables may be taken where $\sqrt{N-3}$ is recommended for higher values instead of $\sqrt{N}$. We have taken $\sqrt{N}$ instead of $\sqrt{N-3}$ because it gives narrower intervals than in the case of $\sqrt{N-3}$ for smaller sample sizes and is almost the same for large samples.

Definition of efficiency in productivity

A worker is said to achieve 100 per cent *efficiency in productivity* if it produces the standard or *specified workload* during the hours of the factory. Table III gives classification of the period of rest and the period of working of a worker at different percentage efficiencies.

TABLE III

Classification of rest and period of work at different percentage efficiencies

Percentage efficiency	Period of work		Period of Rest	
P	Hours	Minutes	Hours	Minutes
100	7	..	..	..
90	6	18	..	42
85	5	57	1	3
80	5	36	1	24
75	5	15	1	45
70	4	54	2	6
65	4	33	2	27
60	4	12	2	48
55	3	51	3	9
50	3	30	3	30

Allowing for rest and tedium of the operation the expected productivity of the worker at the operation at, say, p per cent efficiency and the assumption that the hours of work of the factory are H is given by $\frac{H \times p}{100} \times \frac{1}{\mu^*}$

where μ^* is expressed in hours. The confidence interval for the expected productivity at a level of significance a and for a known sample size N at p per cent efficiency is given by

$$\frac{H \times P}{100} \times \left[\frac{1}{\mu^* + Ta\,\frac{\sigma^*}{\sqrt{N}}}\right]; \quad \frac{H \times P}{100} \times \left[\frac{1}{\mu^* - Ta\,\frac{\sigma^*}{\sqrt{N}}}\right]$$

where $\mu^* + Ta\,\frac{\sigma^*}{\sqrt{N}}$ *and* $\mu^* - Ta\,\frac{\sigma^*}{\sqrt{N}}$

are respectively the maximum and minimum limits of the confidence intervals for the time variable X of the entire operation expressed in hours. Thus it is possible to work out a table of confidence limits of productivity of a worker during a specified period (say, a week, a fortnight or a month) at a given level of significance for different efficiencies.

Table IV gives the confidence limits for the productivity efficiencies during different periods.

TABLE IV

Confidence Intervals for Productivity for Different periods at confidence co-efficient 0·95

Percentage efficiency	Specified period								Expected average produ-tion
	Day		Weeks of six working days		Fortnight 15 Working days		Month 30 workimg days		
	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	Lower Limit	Upper Limit	
90	131 (103)	353 (278)	160 (155)	235 (226)	170 (168)	216 (213)	176 (175)	208 (207)	191
85	123 (97)	334 (263)	152 (146)	222 (214)	161 (159)	204 (201)	166 (165)	197 (195)	180
80	116 (91)	314 (247)	143 (138)	209 (201)	151 (149)	192 (190)	156 (155)	185 (184)	169
75	108 (86)	294 (232)	134 (129)	196 (189)	142 (140)	180 (178)	147 (145)	173 (172)	159
70	102 (80)	275 (217)	125 (120)	183 (176)	132 (131)	168 (166)	137 (136)	162 (161)	148
65	94 (74)	255 (201)	116 (112)	170 (164)	123 (121)	156 (154)	127 (126)	150 (149)	138
60	87 (69)	236 (186)	107 (103)	156 (151)	114 (112)	144 (142)	117 (116)	139 (138)	127
55	80 (63)	216 (170)	98 (95)	143 (138)	104 (103)	132 (130)	107 (107)	127 (126)	116
50	73 (57)	196 (155)	89 (86)	130 (126)	95 (93)	120 (118)	98 (97)	116 (115)	106

The method used here for the calculation of the confidence interval for the productivity is not the one used by most of research workers in statistics, where the standard error for the inverse of quantity distributed $N(\mu, \sigma)$ is given by σ/μ^2 and, therefore, the confidence interval for the inverse of the mean for samples size N of the entire operation in the classical sense is given by

$$\left(\frac{1}{\mu^*} - T\alpha \, \frac{\sigma^*}{\sqrt{N} \; \mu^{*2}}, \; \frac{1}{\mu^*} + T\alpha \, \frac{\sigma^*}{\sqrt{N} \; \mu^{*2}}\right)$$

Compared to classical method our method gives a higher minimum limit and a higher maximum limit for the confidence interval. Moreover for small samples the tolerances are wider in this case. The values of confidence limits arrived by the classical method are given in brackets in Table IV for purposes of comparison.

Discussion

The property of independence of the time variables for the sub-operations is by itself not sufficient to justify the conclusion that when the whole operation is in control at a particular level of significance, the individual sub-operations are simultaneously in control at that level of significance or vice versa. The following possibilities throw light on the procedure to be adopted when the control chart for the daily productivity shows lack of control.

Case I

Let X' be the mean of a sample of size N of the entire operation when the process goes out of control at level of significance *i.e.*

$$\left| \mu^* - X' \right| > T\alpha \frac{\sigma^*}{\sqrt{N}}$$

If $X_4', X_2' \ldots\ldots\ldots X_5'$ are the components of X' from the sub-operations, then by virtue of the inequality

$$\sum_i \frac{\sigma_i^*}{\sqrt{N}} \geqslant \sqrt{\sum_i \left(\frac{\sigma_i^*}{\sqrt{N}}\right)^2}$$

It is mathematically possible that

$$\left| \mu_i^* - X_i' \right| \leqslant T\alpha \frac{\sigma_i^*}{\sqrt{N}} \quad for \ i = 1, 2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

while $$\left| \mu^* - X' \right| \geqslant T\alpha \frac{\sigma^*}{\sqrt{N}}.$$

This result establishes that the sub-operations could be in control when the entire operation is out of control at the level of significance specified.

Case II:

It is possible that $\left| \mu^* - X' \right| > T\alpha \frac{\sigma^*}{\sqrt{N}}$ and the same

time $\left| \mu_i^* - X' \right| \geqslant T\alpha \frac{\sigma i^*}{\sqrt{N}}$ for some values of $1 = 1, 2 \ldots\ldots\ldots 5$.

This shows that some of the sub-operations could show lack of control when the entire operation goes out of control, the level of significance being the same for both.

Thus the procedure should be as follows:—Run the productivity control chart for a certain number of days (a week, a fortnight or a month), leave the process to itself so long as productivity for the period observed is in control, then test for the control of the sub-operations where the size of the sample to be taken is precisely the same as the number of days for which the productivity is observed, leave the process to itself if the sub-operations are in control, otherwise investigate into causes of defects in the sub-operations.

A case might arise when the control chart for the productivity shows points out of control a *significant number of times* in consecutive observations on one side of the control line while the control chart in each case for the sub-operations show perfect control. This phenomenon possibly indicates a shift in the process mean for the sub-operations which is to be investigated and new control limits set up for process control.

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