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An analysis of some differences between one and two-handed industrial work.

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AN ANALYSIS OF SOME DIFFERENCES
BETWEEN ONE AND TWO-HANDED
INDUSTRIAL WORK

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AN ANALYSIS OF SOME DIFFERENCES BETWEEN ONE AND TWO-HANDED INDUSTRIAL WORK

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Much credit is due Professors H. T. Amrine and W. J. Richardson for their valuable advice, suggestions, and encouragement. It was through them also that access was gained into the plants in which the studies were made.

The author is indebted to the Colgate-Palmolive-Peet Company, Jeffersonville, Indiana, the Duncan Electric Company, Lafayette, Indiana, and the Stephen A. Young Company, Flora, Indiana, for making available their personnel and facilities. Sincere appreciation is extended to the personnel, both in the offices and the shops, for their assistance and cooperation without which this study would not have been possible.

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ABSTRACT

In the system of stop watch time study advanced by Dr. M. E. Mundel[1] the rating of an operator's performance is based upon a comparison between the pace or rate of activity of the operator and a standard rate of activity. A correction is then applied for what are now termed allowances and secondary adjustments.[2] One of these secondary adjustments is made for bimanualness or bimanual activity. For the purpose of this discussion a bimanual operation is defined as one requiring the simultaneous symmetrical motion of both hands.

Previous studies[3] conducted at the University of Iowa show a difference in cycle time between one and two handed operations of approximately 30%. The adjustment now applied for bimanual activity is 10% based on the above figure tempered by judgement and experience in application. It was the purpose of this study to substantiate the previous research in part and to determine a more nearly correct value for this adjustment.

It was intended in this experiment to minimize the

1. M. E. Mundel, Systematic Motion and Time Study; (New York, Prentice Hall, 1947) p. 128.

2. M. E. Mundel, Motion and Time Study Principles and Practice; (New York, Prentice Hall, 1950) Chapter 18 (Manuscript before press.)

3. R. M. Barnes, M. E. Mundel, and J. M. MacKenzie, "Studies of One and Two-Handed Work," (University of Iowa Studies in Engineering, Bulletin 21, 1940).

error in the previous laboratory study believed attributable to inexperience and laboratory conditions. For that reason the subjects in this study were experienced operators doing industrial jobs requiring bimanual activity. A total of eight operators on five different operations were selected. Each operator performed the operation first bimanually, then with the preferred hand alone and finally with the non-preferred hand. A short practice period was included between each phase.

Each study was recorded on 16 mm. motion picture film with time included by means of having a microchronometer placed in the field of view. This procedure made possible a very accurate determination of cycle time. A sufficient number of cycles were photographed to obtain a statistically reliable mean cycle time for each operation.

From the mean of the cycle times there was calculated a percent increase in cycle time required for bimanual activity over that required using the preferred hand. The mean percent increase in cycle time was found to be 17.852%. Since the percent increase in cycle time is symmetrically distributed about the mean, the mean is the best measure of central tendency.[4] It is concluded then that a value of 18% is more nearly the correct adjustment to be applied for bimanualness.

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4. P. G. Hoel, Introduction to Mathematical Statistics; (New York, Wiley and Sons, Inc., 1947) p. 8, 18.

AN ANALYSIS OF SOME DIFFERENCES BETWEEN ONE AND TWO-HANDED INDUSTRIAL WORK

INTRODUCTION

"Stop watch time study is used to find the amount of time necessary to accomplish a unit of work using a given method under given conditions of work, by a worker possessing a specified amount of skill on the job and a specified aptitude for the job, when working at a pace that will produce, within a unit of time, a specified physical effect upon him."[1]

There are four principal steps in the mechanics of taking a stop watch time study, namely:

1. Recording the method.
2. Recording the time.
3. Rating the operator.
4. Application of allowances and secondary adjustments.

It is a very small portion of the fourth step listed which is the subject of this study.

In the system of stop watch time study[2] advanced by Dr. M. E. Mundel, rating, which is the third step mentioned in the preceding paragraph, is accomplished by relating

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1. Mundel, Systematic, p. 128.

2. Ibid.

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1. Mundel, Systematic, p. 128.
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the performance of an operator to a standard by a comparison of pace alone. The fallacy of such a system without secondary adjustments for job difficulty is apparent when one considers the following exaggerated case. Suppose the rate of activity of a worker handling fifty pound weights is compared to that of a man dealing cards as a standard. Due to job difficulty the pace at which the former works cannot possibly approach that rate of activity which is the standard. An adjustment is therefore made to the rating for the degree of job difficulty - in this case the weight handled. In a like manner, but to a lesser degree, an adjustment must be made for bimanual activity.

In studies[3] conducted at Iowa University there was found to be an increase in cycle time of approximately 30% when performing a simple operation bimanually over that needed to perform the operation with only one hand. From experience in the application of the adjustment for bimanualness it has been determined that a value of 30% is too great and an adjustment of 10% is now being used.

An examination of the Iowa studies suggests that the error believed to be included in the results might be attributed to a lack of experience on the part of the operators. The operators were students whose performances were recorded after a minimum of training. Equal training or practice periods were allocated to each phase of

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3. Barnes, Mundel, MacKenzie, Op. Cit.

the study. The operators performed the operation first with only one hand and then bimanually. Although the operation was a relatively simple one, it is possible that a marked degree of proficiency was attained using only one hand and that the same degree of proficiency was not reached in the bimanual operation.

PURPOSE

The purpose of this investigation is to determine the adjustment for bimanualness which should be applied in making a stop watch time study when using a pace-rating system.

PROCEDURE

This experiment was designed primarily to eliminate lack of experience as a factor influencing the results. Operators were selected who had considerable experience or who demonstrated the equivalent in aptitude and proficiency on bimanual jobs in industry. It appears reasonable to conclude that these operators must possess equal skill in using only one hand separately to do the identical job. Any lack of familiarity or awkwardness in performing the job with one hand was minimized by allowing short practice periods for the operators.

In addition it was intended to minimize all variables except those which are uniquely attributable to bimanual activity. Jobs were selected which required a minimum of eye-hand coordination in order to minimize the effect of that variable for which a separate correction is made. The weights of parts handled by the operator were negligible and no part of the cycle was machine paced. It might appear that a wide range of job cycle times is desirable for a study of this kind. However, all but two jobs selected had comparatively short cycle times. A short cycle was characteristic of the jobs from which the selection for this study was made and is typical of a wide variety of bimanual jobs. Eight operators on five different jobs were selected.

Once the operator was selected, the purpose, procedure

and scope of the study were explained to him. He was instructed to perform each phase of the study using exactly the same method and at the maximum pace which he could attain. He was assured that the motion pictures would not be used by the company in setting standards or in any way which would affect the job either directly or indirectly. The operator was given an opportunity to ask any questions he wished concerning the procedure and objectives of the study. In that way it was attempted to obtain the complete confidence and cooperation of the operator before the study was begun.

The operator first performed the operation bimanually, then with the preferred hand, and finally with the non-preferred hand. A brief practice period was allocated between each phase to enable the operator to become adapted to performing the operation with only one hand. The operator's performance was recorded using a motion picture camera. A sufficient number of cycles were photographed to insure a statistically reliable average cycle time.

The motion pictures were taken on Eastman Kodak Super XX film at 16 frames per second using an Eastmen Kodak Cine Special 16 mm. camera with an f 1.9 lens. Photoflood lights were used to supplement the light normally available to the worker in order to insure satisfactory exposures. A microchronometer was placed in the field of view of the camera in order to provide a measure of time on the film. The film is available for reference in the Motion and Time and scope of the study were explained to him. He was instructed to perform each phase of the study using exactly the same method and at the maximum pace which he could attain. He was assured that the motion pictures would not be used by the company in setting standards or in any way which would affect the job either directly or indirectly. The operator was given an opportunity to ask any questions he wished concerning the procedure and objectives of the study. In this way it was attempted to obtain the complete confidence and cooperation of the operator before the study was begun.

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Study Laboratory, Purdue University.

After the film was processed, it was analyzed. For this work, a small, inexpensive, hand-crank operated motion picture projector was used to view the film in a darkened room. The projector was fitted with a heat dispensing adaptor in order that a single frame could be viewed for any length of time without danger of burning the film. The analysis consisted of determining and recording the time required for each cycle. Those cycles were not included which incorporated fumbles or irregularly occuring elements not inherent in the operation. The procedure used in analyzing the film was to pick out a well defined therblig[4] in the operation and record the time value shown on the microchronometer each time that therblig occured. The difference between the successive time values becomes the cycle time which was computed and recorded.

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4. Mundel, Systematic, p. 105.

DATA

The data for this study consists of a tabulation of the cycle times required by each operator to perform his particular operation bimanually, with the preferred hand, and with the non-preferred hand. These tables, Tables 3 through 10, and job descriptions, Figures 3 through 7, appear in the Appendix.

In each case a sufficient number of cycles were photographed to obtain a statistically reliable mean cycle time for each set of data. In order to substantiate this, one has only to apply the formula:[5]

$$N' = \left(\frac{40\sqrt{N\Sigma t^2 - (\Sigma t)^2}}{\Sigma t} \right)^2$$

where,

N^1 = the number of cycles required to establish the probability that 95 times out of 100 the average cycle time will be within ±5% of the true average representing the observed performance.

N = the number of cycles recorded.

t = the individual cycle times.

For each set of data N^1 was found to be smaller than N, and thus the reliability of the mean at the 5% level was established. The 5% confidence level is an industrially

5. M. E. Mundel, "How Many Readings in a Time Study," ("Modern Management" August, 1949).

accepted standard. For mathmatical computations see Table 11.

RESULTS

The mean cycle time required by each operator for each phase of the operation is recorded in Table 1.

Table 1

MEAN JOB CYCLE TIMES. ŧ

Oper- ation	Oper- ator	Mean Cycle Time (winks) Bi- manually	Preferred Hand	Non-preferred Hand
1	1	36.000	30.893	31.710
	2	34.333	28.210	28.270
	3	40.133	33.051	33.088
2	1	34.895	30.463	31.571
	2	45.357	35.000	40.533
3	1	41.621	38.147	40.625
4	1	250.167	222.818	222.000
5	1	177.452	150.850	156.667

A wink is a 1/2000th part of a minute.

From the above results there was computed the percent increase in cycle time required when performing bimanually and when using the non-preferred hand over that required when using the preferred hand. That information is shown in Table 2.

RESULTS

The mean cycle time required by each operator for each phase of the operation is recorded in Table 1.

Table 1

MEAN JOB CYCLE TIMES. T

Operation	Operator	Mean Cycle Time (winks) Bi-manually	Preferred Hand	Non-preferred Hand
1	1	26.000	30.693	31.710
	2	24.225	28.210	28.270
	3	40.133	33.031	37.088
2	1	34.996	30.463	41.971
	2	45.347	35.000	40.555
3	1	41.621	36.147	40.626
4	1	260.167	223.016	229.000
5	1	177.453	150.050	155.557

A wink is a 1/2000th part of a minute.

From the above results there was computed the percent increase in cycle time required when performing bi-manually and when using the non-preferred hand over that required when using the preferred hand. That information is shown in Table 2.

Table 2

PERCENT INCREASE IN CYCLE TIME
OVER PREFERRED HAND TIMES

Operation	Operator	Bimanually	Non-Preferred Hand
1	1	16.531	2.645
	2	21.705	0.213
	3	21.427	0.112
2	1	14.549	3.637
	2	29.591	15.808
3	1	9.107	6.496
4	1	12.274	-0.368
5	1	17.635	3.856

The mean percent increase in cycle time for bimanual operation over that required using the preferred hand alone is determined from the above to be 17.852%.

DISCUSSION OF RESULTS

Since the cycle times in two of the eight jobs studied were comparatively long, it was believed desirable to see what effect, if any, the length of cycle time had upon the percent increase in cycle time. A simple correlation coefficient between the two was calculated using the formula:

$$r = \frac{N\Sigma xy - \Sigma x\Sigma y}{\sqrt{[N\Sigma x^2 - (\Sigma x)^2][N\Sigma y^2 - (\Sigma y)^2]}}$$

$$= 0.34$$

This correlation coefficient is not significantly different from zero and, therefore, there is little correlation between the two items. To further substantiate this result a line of least squares was calculated for this data and was found to have a slope of +.029. The scattergram for this data is shown in Figure 1. For mathmatical computations see Table 12.

A histogram showing the frequency distribution of the percent increase in cycle times in the class intervals 0-5%, 5-10%, 10-15%, 15-20%, 20-25% and 25-30% is shown in Figure 2. It is clearly evident that the observed values are quite symmetrically distributed about the mean which was found to be 17.852% and that, therefore, the mean value is the best measure of central tendency.[6]

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6. Hoel, loc. cit.

This value of 18% is clearly significantly different from the 30% which was previously found in the Iowa studies.[7] It is indeed probable that the major contributing factor to that difference is the inexperience of the operators in the previous experiment. That factor has been minimized in the present study. It is concluded that the 18% increase in cycle time is due almost entirely to what might be termed difficulty of coordination in bimanual activity.

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7. Barnes, Mundel, and McKenzie, op. cit.

CONCLUSIONS

Since it has been shown that an average operator requires 18% longer to complete a cycle bimanually than when using only one hand, it follows that he must be operating at a pace 18% slower in the former case. Yet in each case he was performing at a rate of activity which represented his maximum effort. Therefore, the rating assigned to the operators performance should be identical in both instances. Using pace alone as a criterion, however, the operator when performing bimanually would be rated 18% lower than when using only the preferred hand. To make the ratings identical, a correction of 18% must be added to the rating assigned to the bimanual operation. Therefore, it is concluded that a secondary adjustment of 18% must be made to compensate for job difficulty in bimanual operations using a pace-rating system of time study.

APPENDIX

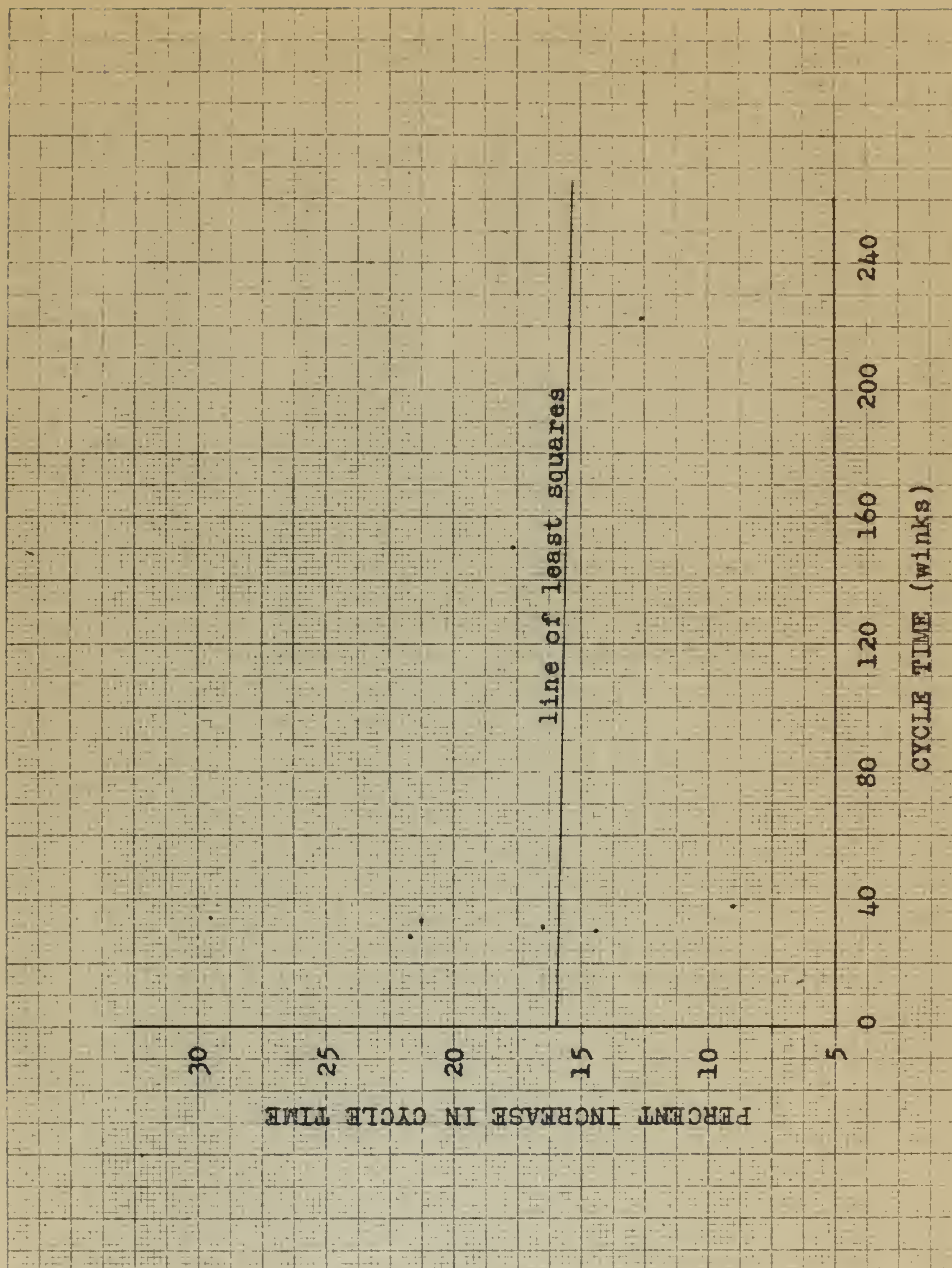

Figure 1. Mean cycle time vs. percent increase in cycle time for bimanual over preferred hand activity.

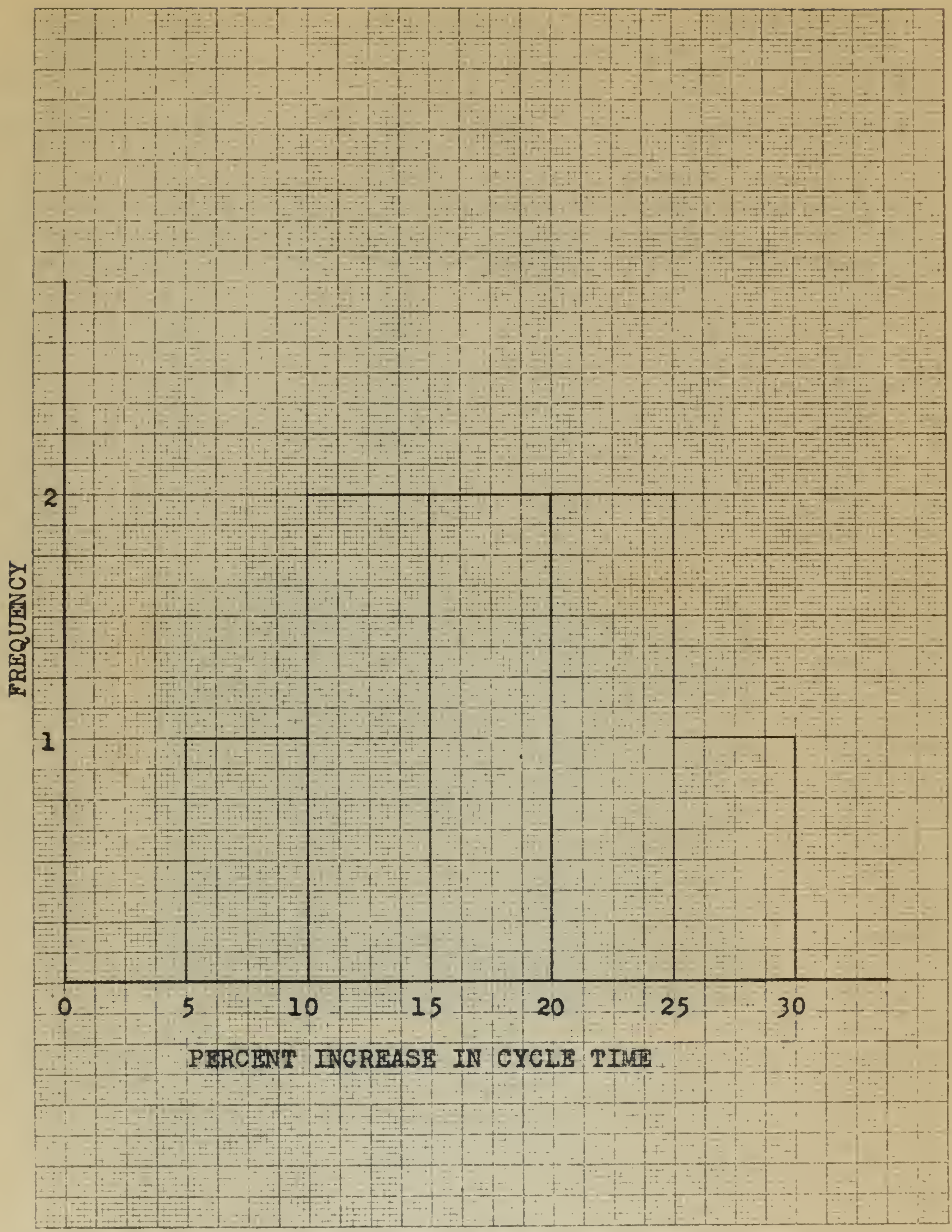

Figure 2. Histogram showing frequency distribution of percent increase in mean cycle time.

Operation: Filling carton with individual boxes of Veto.

Description

Left Hand	Therblig	Right Hand
Get box of Veto	TE, G, TL	Get box of Veto
Place in carton	P, A, RL	Place in carton

The therblig underlined performed by the right hand is the beginning of the cycle for the purposes of this time analysis.

Figure 3. Workplace for Packaging Veto.

Table 3

VETO PACKAGING #1

Bimanually T	Bimanually t	Preferred Hand T	Preferred Hand t	Non-Preferred Hand T	Non-Preferred Hand t
595		315		784	
630	35	369*		814	30
675	35	013*		845	31
768*		049	36	876	31
806	38	573*		911	35
919*		566	29	132*	
954	35	616*		165	33
000*		665*		200	35
036	36	697*		247*	
069	33	728	31	273	26
230*		867*		300	27
267	37	897	30	330	30
307	40	955*		373*	
351*		030*		411*	
385	34	068*		543	32
423	38	100	32	575	32
572*		144*		606	31
612*		171	27	640	36
650	38	205	34	675	35
682	32	235	30	703	28
729*		265	30	734	31
840*		302	37	761	27
872	32	393*		793	32
912	40	434*		827	34
950	38	464	30	860	33
978	28	575*		022*	
026*		548	33	050	28
315*		574	26	078	28
350	35	620*		116*	
386	36	650	30	154*	
516*		680	30	185	31
601*		710	30	236*	
642	41	740	30	267	31
855*		771	31	300	33
895	40	848*		332	32
940*		888*		074*	
975	35	920	32	413*	
011	36	960*		549*	
		996	36	583	34
		024	28	615	32
		056	32	650	35
		086	30	685	35
		130*		720	35
		160	30	752	32
		193	33	780	28
		226	33	812	32
		323*		840*	
		351	28	871	31
		378	27	046*	
		415*		078	32
				111	33
				150*	
				188*	
				222	34
Σt	792		865		1205
N	22		28		38
$\bar{t}$	36.000		30.893		31.710

T = elapsed time, t = cycle time, N = number of cycles
$\bar{t}$ = mean cycle time. Note: Symbols apply to Tables 3 - 10.
*Cycle time not included because of fumble or irregularly occuring element.

Table 4

VETO PACKAGING #2

Bimanually T	Bimanually t	Preferred Hand T	Preferred Hand t	Non-Preferred Hand T	Non-Preferred Hand t
210*		380		745	
253*		406	26	770	25
293	40	456*		793	23
327	34	509*		818	25
377*		535	26	847	29
473*		558	23	860*	
510	37	591	33	885	25
549	39	621	30	055*	
587	38	652	31	095*	
622	35	743*		125	30
658	36	770	27	158	33
753*		797	27	183	25
792	39	830	33	208	25
830	38	865	35	245	37
869	39	897	32	269	24
911*		936*		294	25
948	37	964	28	376*	
033*		985	21	405	29
065	32	008	23	434	29
099	34	037	29	463	29
158*		059*		493	30
187	29	092	33	528	35
218	31	192*		560	32
300*		220	28	586	26
334	34	968*		612	26
376*		352*		640	28
410	34	380	28	668	28
442	32	411	31	695	27
469	27	436	25	787*	
550*		460	24	826*	
580	30	490	30	856	30
622*		520	30	885	29
659	37	552	32	966*	
693	34	638*		005*	
728	35	664	26	034	29
825*		690	26	067	33
857	32	740*		110*	
895	38	785*		148*	
934	39	828*		177	29
962	28	867*		296*	
990	28	946*		225	29
083*		974	28	254	29
122	39	998	24	284	30
157	35	085*		324*	
193	36	111	26	452	28
223	30	142	31	480	28
250	27	172	30	507	27
		202	30	532	25
		234	32	557	25
		264	30	587	30
		291	27		
		317	26		
		361*			
		386	25		
		412	26		

	Bimanually	Preferred Hand	Non-Preferred Hand
Σt	1133	1072	1046
N	33	38	37
$\bar{t}$	34.333	28.210	28.270

*Cycle time not included because of fumble or irregularly occuring element.

Table 5

VETO PACKAGING #3

Bimanually T	Bimanually t	Preferred Hand T	Preferred Hand t	Non-Preferred Hand T	Non-Preferred Hand t
265*		142*		227*	
308	43	193*		251	24
347	39	246*		282	31
403*		304*		324*	
446	43	337	33	356	32
555*		376	39	566*	
590	35	426*		598	32
631	41	486*		632	34
670	39	531*		666	34
707	37	562	31	699	33
750	43	623*		742*	
837*		670*		770	28
877	40	705	35	799	29
938*		737	32	830	31
985	47	450*		863	33
049*		492	42	894	31
084	35	528	36	043*	
201*		565	37	075	32
237	36	635*		108	33
275	38	759*		142	34
346*		789	30	175	33
384	38	813	24	215	40
422	38	843	30	249	34
547*		876	33	280	31
586	39	962*		314	34
624	38	992	30	345	31
664	40	025	33	376	31
708	44	064	39	428*	
747	39	094	30	573*	
863*		130	36	613	40
900	37	172	42	666*	
938	38	202	30	696	30
977	39	237	35	736	40
015	38	270	33	767	31
054	39	300	30	804	37
166*		330	30	836	32
206	40	443*		878	42
255	49	470	27	921	43
328*		496	26	958	37
367	39	527	31	989	31
415	48	560	33	145*	
507*		596	36	174	29
552	45	628	32	202	28
		659	31	248*	
		687	28		
		715	28		
		757	42		
		782	25		
		899*			
		930	31		
		961	31		
		004	43		
		046	42		
		092*			
		125	33		

	Bimanually	Preferred Hand	Non-Preferred Hand
Σt	1204	1289	1125
N	30	39	34
$\bar{t}$	40.133	33.051	33.088

*Cycle time not included because of fumble or irregularly occuring element.

Operation: Filling carton with individual tooth powder cans.

Description

Left Hand	Therblig	Right Hand
Get can of tooth powder	TE, G, TL	Get can of tooth powder
Place in carton	P, A, RL	Place in carton

The underlined therblig performed by the right hand is the start of the work cycle for the purpose of this time analysis.

Figure 4. Workplace for tooth powder packaging.

Table 6

TOOTH POWDER PACKAGING #1

Bimanually T	Bimanually t	Preferred Hand T	Preferred Hand t	Non-Preferred Hand T	Non-Preferred Hand t
602*		540*		368*	
681*		567	27	405*	
730*		619*		439	34
762	32	649	30	560*	
888*		677	28	590	30
927	39	707	30	616	26
976*		735	28	647	31
015	39	764	29	687*	
092*		795	31	718	31
123	31	822	27	761*	
255*		945*		802*	
287	32	976	31	832	30
324	37	004	28	862	30
360	36	035	31	891	29
406*		064	29	929*	
570*		095	31	036*	
601	31	124	29	076*	
635	34	155	31	110	34
670	35	192*		140	30
705	35	222	30	184*	
738	33	255	33	248*	
879*		445*		280	32
918	39	535*		330*	
952	34	570	35	372*	
023*		670*		407	35
123*		702	32	444	37
265*		734	32	475	31
295	30	762	28	611*	
330	35	793	31	645	34
377*		825	32	684*	
415	38	926*		725*	
455	40	957	31	764*	
608*		985	28	795	31
645*		017	32	827	32
686*		055*		857	30
728*		085	30	887	30
761	33	117	32	918	31
805*		147	30	953	35
926*		183	36	984	31
982*		216	33	155*	
		246	30	183	28
		288*		213	30
		425*		247	34
		454	29	287*	
		492*		318	31
		522	30	351	33
		554	32	385	34
		585	31		
		626*			
		685*			
		720	35		
		751	31		
		781	30		
		930*			
		956	26		
		986	30		
Σt	663	1249		884	
N	19	41		28	
$\bar{t}$	34.895	30.504		31.571	

*Cycle time not included because of fumble or irregularly occuring element.

Table 7

TOOTH POWDER PACKAGING #2

Bimanually		Preferred Hand		Non-Preferred Hand	
T	t	T	t	T	t
620*		425*		355*	
661	41	459	34	392	37
715*		492	33	440*	
785*		525	33	496*	
829	44	558	33	580*	
917*		593	35	625	45
052*		640*		668	43
095	43	675	35	710	42
181*		734*		765*	
245*		767	33	805	40
292	47	803	36	901*	
345*		914*		944	43
480*		947	33	985	41
525	45	980	33	024	39
572	47	018	38	065	41
635*		054	36	123*	
688*		107*		165	42
737	49	151*		206	41
862*		185	34	248	42
901	39	255*		287	39
949	48	295	40	326	39
129*		332	37	365	39
267*		370	38	482*	
310	43	485*		567*	
370*		554*		637*	
418	48	591	37	680	43
474*		627	36	727	47
522	48	666	39	767	40
647*		711*		805	38
690	43	763*		845	40
740	50	855*		885	40
		885	30	930	45
		985*		970	40
		094*		105	35
		132	38	147	42
		170	38	182	35
		197	27	230*	
		232	35	283*	
		270	38	326	43
		299	29	365	39
		345*		438*	
		382	37	490*	
		419	37	532	42
		452	33	574	42
		485	33	640	36
		584*			
		620	36		
		650	30		
		689	39		
		723*			
		760	37		

	Bimanually	Preferred Hand	Non-Preferred Hand
Σt	635	1190	1259
N	14	34	31
$\bar{t}$	45.357	35.000	40.533

*Cycle time not included because of fumble or irregularly occuring element.

Operation: Filling carton with bottles of Halo.

Left Hand	Description Therblig	Right Hand
Get bottle of Halo	TE, G, TL	Get bottle of Halo
Place in carton	P, A, RL	Place in carton

The therblig underlined performed by the right hand represents the start of a cycle for the purpose of this time analysis.

Figure 5. Workplace for Packaging Halo.

Operation: Filling carton with bottles of Halo.

Description

Left Hand	Therblig	Right Hand
Get bottle of Halo	TE, <u>G</u>, TL	Get bottle of Halo
Place in carton	P, A, RL	Place in carton

The therblig underlined performed by the right hand represents the start of a cycle for the purpose of this time analysis.

Figure 5. Workplace for Packaging Halo.

Table 8

HALO PACKAGING

Bimanually T	Bimanually t	Preferred Hand T	Preferred Hand t	Non-Preferred Hand T	Non-Preferred Hand t
499*		872*		890*	
544	45	911	39	931	41
673*		960*		973	42
712	39	040*		040*	
756	44	085	45	090*	
795	39	124	39	132	42
835	40	257*		170	38
878	43	300	43	220*	
136*		337	37	282*	
185	49	372	35	333*	
218	33	423*		388*	
258	40	459	36	523*	
302	44	498	39	563	40
422*		540	42	610	47
460	38	578	38	652	42
502	42	624	46	717*	
542	40	664	40	757	40
582	40	699	35	808*	
628	46	828*		847	39
754*		878*		905*	
796	42	916	38	960*	
842	46	955	39	010*	
880	38	008*		065*	
920	40	046	38	227*	
979*		085	39	265	38
107*		122	37	307	42
148	41	235*		347	40
189	41	274	39	459*	
226	37	312	38	495	36
264	38	438*		540	45
310	46	474	36	575	35
417*		513	39	618	43
454	37	549	36		
528*		599*			
564	36	636	37		
603	39	673	37		
656*		711	38		
796*		748	37		
836	40	790	42		
877	41	827	37		
917	40	863	37		
960	43	003	40		
007	47	037	34		
131*		068	31		
172	41	102	34		
216	44				
263	47				
310	47				
357	47				

	Bimanually	Preferred Hand	Non-Preferred Hand
Σt	1540	1297	650
N	37	34	16
$\bar{t}$	41.621	38.147	40.625

*Cycle time not included because of fumble or irregularly occuring element.

Operation: Assembling faucet sub-assembly.

Description

Left Hand	Therblig	Right Hand
Get saw	TE, G, P	Get saw
Assemble with fixture	A, RL	Assemble with fixture
Get washer	TE, G, TL	Get washer
Assemble with screw	P, A, RL	Assemble with screw
Get swivel	TE, G, P	Get swivel
Assemble with screw	A, RL	Assemble with screw
Disassemble from fixture	TE, G, TL	Disassemble from fixture
Assemble with tightening board	P, <u>A</u>, RL	Assemble with tightening board

The underlined Therblig represents the performed act by the right hand beginning a cycle for the purposes of this time analysis.

Figure 6. Workplace for assembling faucet sub-assemblies.

Table 9

FAUCET SUB-ASSEMBLY

Bimanually		Preferred Hand		Non-Preferred Hand	
T	t	T	t	T	t
238*		118*		988*	
501	263	372	254	212	224
725	224	590	218	436	224
980	255	808	218	662	226
259	271	043	235	876	214
495	236	308*		160*	
759	264	511	203		
024	265	725	214		
426*		922	197		
696	270	317*			
985*		530	213		
410*		796*			
700*		035	239		
926	226	284	249		
140	214	456*			
391	251	741*			
689*		770*			
065*		981	211		
328	263				
626*					

	Bimanually	Preferred Hand	Non-Preferred Hand
Σt	3002	2451	888
N	12	11	4
$\bar{t}$	250.167	222.154	222.000

*Cycle time not included because of fumble or irregularly occuring element.

Operation: Assembling watt-hour meter sub-assembly.

Description

Left Hand	Therblig	Right Hand
Get sleeve	TE, G, TL	Get sleeve
Assemble with fixture	P, A, RL	Assemble with fixture
Get washer	TE, G, TL	Get washer
Assemble with fixture	P, A, RL	Assemble with fixture
Get screw	TE, G, TL	Get screw
Assemble with sleeve and washer	P, A, RL	Assemble with sleeve and washer
	DA, RL	Trip fixture release

The therblig underlined performed by the right hand represents the beginning of a cycle for the purpose of this time analysis.

Figure 7. Workplace for assembling watt-hour meter sub-assembly.

Table 10

ASSEMBLING SLEEVE AND WASHER TO BOLT

Bimanually		Preferred Hand		Non-Preferred Hand	
T	t	T	t	T	t
750*		037*		707*	
918	168	235	198	874	167
135	217	427	192	054	180
352*		553	126	179	125
598*		740	187	316	137
788	190	867	127	483	167
009	221	135	168	645	162
152	143	255*		810	165
556*		430	175	958	148
775	219	586	156	093	135
915	140	740	154	231	138
084	169	874	136	380	149
239	155	059	185	526	146
385	146	237	178	654	128
580	195	704*		785	131
791	211	874	170	930	145
960	169	015	141	111	181
103	143	152	137	647*	
338*		304	152	867*	
496	158	456	152	996	129
656	160	617	161	177	181
841	185	742	125	326	149
011	170	876	134	480	154
211	200	012	136		
770*					
946	176				
089	143				
234	145				
431	197				
601	171				
805	204				
009	204				
237*					
404	167				
594	190				
775	181				
962	187				
139	177				

	Bimanually	Preferred Hand	Non-Preferred Hand
Σt	5501	3290	3017
N	31	21	20
$\bar{t}$	177.452	156.667	150.850

*Cycle time not included because of fumble or irregularly occuring element.

Table 11

CALCULATION OF N^1

Operation	Operator		Σt	Σt^2	$N\Sigma t^2$
1	1	Preferred Hand	865	26921	753788
		Non-preferred	1205	38459	1461442
		Bimanually	792	28716	631752
	2	Preferred Hand	1082	30644	1164472
		Non-preferred	1046	29916	1106892
		Bimanually	1133	39391	1299903
	3	Preferred Hand	1289	43515	1697085
		Non-preferred	1125	37791	1284894
		Bimanually	1204	48692	1460760
2	1	Preferred Hand	1249	38235	1567635
		Non-preferred	884	28064	785792
		Bimanually	663	23307	442833
	2	Preferred Hand	1190	41960	1426640
		Non-preferred	1216	49486	1484580
		Bimanually	635	28941	405174
3	1	Preferred Hand	1297	49772	1692486
		Non-preferred	650	26550	424800
		Bimanually	1540	64586	2389682
4	1	Preferred Hand	2888	549615	60457650
		Non-preferred	888		
		Bimanually	3002	755370	9064440
5	1	Preferred Hand	3017	461381	9227620
		Non-preferred	3290	526104	11048184
		Bimanually	5501	994191	30819921

Operation	Operator		$(\Sigma t)^2$	$N\Sigma t^2 - (\Sigma t)^2$	N	N^1
1	1	Preferred Hand	748225	5563	28	11.9
		Non-preferred	1452025	9417	38	10.4
		Bimanually	627264	4488	22	11.4
	2	Preferred Hand	1149184	15288	38	20.9
		Non-preferred	1094116	12776	37	18.7
		Bimanually	1283689	16214	33	20.25
	3	Preferred Hand	1661521	35564	39	34.3
		Non-preferred	1265625	19269	34	24.3
		Bimanually	1449616	11144	30	12.3
2	1	Preferred Hand	1560001	7634	41	7.9
		Non-preferred	781456	4336	28	10.0
		Bimanually	439569	3264	19	11.9
	2	Preferred Hand	1416100	10540	34	11.9
		Non-preferred	1478656	5924	30	6.4
		Bimanually	403225	1949	14	7.4
3	1	Preferred Hand	1682209	10277	34	10.1
		Non-preferred	422500	2300	16	8.7
		Bimanually	2371600	18082	37	12.2

Table 11 (Continued)

Oper-ation	Oper-ator		$(\Sigma t)^2$	$N\Sigma t^2 - (\Sigma t)^2$	N	N^1
4	1	Preferred Hand	6007401	38364	11	10.1
		Non-preferred			4	
		Bimanually	9012004	52436	12	9.3
5	1	Preferred Hand	9102289	125331	20	22
		Non-preferred	1082410	224084	21	33
		Bimanually	30261001	558920	31	29.4

Table 12

COMPUTATION OF CORRELATION COEFFICIENT
BETWEEN MEAN CYCLE TIMES FOR PREFERRED HAND OPERATION
AND PERCENT INCREASE IN CYCLE TIME FOR BIMANUAL OPERATION

Operation	Operator	Cycle Time x	Percent Increase y
1	1	30.893	16.531
	2	28.210	21.705
	3	33.051	21.427
2	1	30.463	14.549
	2	35.000	29.591
3	1	38.147	9.107
4	1	222.818	12.610
5	1	150.850	17.635

Σx	569.432	Σy	143.155
Σx^2	78829.607	Σy^2	2843.741
$\Sigma x \Sigma y$	81325.709	Σxy	9127.445

Line of Least Squares.

$$a = \text{slope} = \frac{N\Sigma xy - \Sigma x \Sigma y}{N\Sigma x^2 - (\Sigma x)^2} = -.027$$

$$b = y \text{ intercept} = \frac{\Sigma x^2 \Sigma y - \Sigma x \Sigma xy}{N\Sigma x^2 - (\Sigma x)^2} = 15.972$$

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