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Chapter Author: Harry Jerome

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CHAPTER VI

MEASURES OF CHANGE IN MECHANIZATION

In preceding chapters we have sketched the observed tendencies towards increasing mechanization, first in selected manufacturing industries, then in the non-manufacturing industries and finally in the handling of materials, which is more or less common to all. The reader has doubtless gained the impression that mechanization in the post-War decade proceeded along many lines and with somewhat exceptional rapidity. Can we state this tendency towards mechanization in a more generalized form than by describing the developments peculiar to each industry, and in a form reasonably comparable from industry to industry and from period to period? Just how fast and in what ways has mechanization progressed? Can we measure it or at least delineate its main lines of advance?

For purposes of measurement the concept of mechanization requires a more precise denotation. Here we are limiting it to power mechanization, that is, to processes and methods utilizing generated power. So limited we find several possible ways of measuring its extent. First we may take the amount of power used, or the more readily available figure of rated horsepower capacity of power equipment. But this measure does not give us a ratio of machine work to non-machine work. To obtain such a ratio we may turn to the proportion of product that arises from mechanical as compared with manual methods, and this machine output ratio

is obviously significant in the few instances where it is available. But even this figure does not correctly indicate the proportion of workers engaged in the mechanized process, for 75 per cent of an industry's output might be produced by 25 per cent of the workers if they were equipped with highly productive machinery and the other 75 per cent were using antiquated hand methods. It will be noted that the *machine labor ratio* based upon the proportion of machine workers to the total labor force is a measure of mechanization that facilitates a comparison of the degree of mechanization between two processes in the same industry (see Ch. VII).

A second possible measure of this type is the ratio of expense for labor to the total cost of production. The ratio of wages to value added by manufacture (as a rough measure of the *labor expense ratio*) can be determined from census data by industries, but not for the several processes in an industry. However, if sufficiently detailed cost accounting records were available, it is conceivable that ratios of labor expense to total expense could be computed for each process and used as rough measures of relative mechanization. The labor expense ratio, it will be noted, is affected not only by the number of wage earners, but also by relative wage rates and hence by the grade of labor in so far as wage rates are determined by differences in the type of labor. Another possible measure is the equipment ratio—the dollar value per worker of the power equipment in use.[1]

The horsepower ratio, the machine output ratio, the machine labor ratio, and the labor expense ratio are all more or less *general measures* of mechanization in that they are

[1] Colonel M. C. Rorty remarks that a very interesting, but still not wholly significant, figure might be K. W. hours per unit of output from year to year for a given establishment or industry; and that *intensified illumination* is probably a not unimportant element in increasing power consumption.

applicable (assuming appropriate data are available) to all industries. In contrast are various specific measures which indicate the extent of use of specified labor-saving devices and are consequently limited in their application to the particular industries in which such devices are used.

The several general measures of mechanization do not give precisely the same result when the degree of mechanization between industries or at different periods in the same industry is compared, partly because they refer to somewhat different aspects of the phenomenon of mechanization, and partly because of the inadequacy of the data and complicating factors whose influence cannot be eliminated. There is no adequate single quantitative measure of the extent of the increasing substitution of machines for human effort. We must resort to the composite picture afforded by several phenomena. Though no one of these alone tells the whole story, jointly they throw much light on the trend in mechanization.

Of the several measures mentioned, the most readily available is the rated capacity of prime movers and motors operated by purchased power, expressed in terms of horsepower.[2] Rated horsepower statistics are published in considerable detail, particularly for manufacturing. But the statistics of horsepower, though useful and important, are, as will be explained more fully in subsequent paragraphs, inadequate in two respects: first, they do not give a perfect record of the changes in power used or even of installed power equipment; second, the changes in power per worker, even if precisely measured, are not a complete story of the changes in mechanization. In fact, some important mechanical improvements actually result in a decrease rather than an

[2] Prime movers are steam engines and turbines, internal combustion engines, and water wheels and water turbines.

increase in power requirements. Consequently it is appropriate to supplement our analysis of the capacity of installed power equipment with such other evidence as is available to indicate the changing degree of mechanization.

We are concerned in this chapter with measures that facilitate comparisons of change in mechanization—of the degree of mechanization at different periods—rather than comparisons as in Chapter VII of differences in degree of mechanization at a given time between industries, processes or producing areas. The general measures available for chronological comparisons are not so numerous or adequate as those usable for comparisons of currently existing differences. The ratio of wages to value added by manufacture is available but is of somewhat limited usefulness. The growth of the machine-producing industry is itself a clue to the changing importance of the machine. Also, in addition to the general measures, there are available for particular industries or processes various indicators of change in the use of specified labor-saving devices. For a few processes, such as coal-undercutting in mining, the year-to-year changes in the proportion of output produced by mechanical equipment are on record; for others the proportion of operators equipped with specified labor-saving devices. The annual records of the number of specified labor-saving devices sold, or of the total number in use, afford some additional evidence of changing mechanization. Data of this type for numerous series are given in the several tables in Appendix A.

Growth in the Use of Power

The most generally available and most frequently used measure of increasing mechanization is horsepower per

worker.[8] While some useful information is available for several other industries, such as agriculture, mining and transportation, horsepower statistics are most complete for manufacturing.

LIMITATIONS OF POWER DATA

Power equipment and the number of wage earners in manufacturing have been compiled in the census of manufactures for 1869, 1879, 1889, 1899, 1904, 1909, 1914, 1919, 1923, 1925, 1927 and 1929. Before examining the statistics of horsepower per wage earner computed from these data, we should note their limitations:

1. The scope of the *Census of Manufactures* has changed in such a way that for neither wage earners nor rated horsepower are available data strictly comparable from period to period.

2. The increasing use of electric power is probably accompanied by a decreasing ratio between the machines operated by power and the rated capacity of power equipment.

3. Rated capacity is at best an imperfect index of power actually used.

4. Even power actually used would not be an entirely adequate measure of mechanization.

Changes in the scope of the Census

Prior to 1904 the *Census of Manufactures* covered not only the factory system proper but also various hand and neighborhood industries. In 1904 and subsequent censuses

[8] Horsepower as used in the *Census of Manufactures* refers to the rated capacity of prime movers and motors driven by purchased current and not to the amount of power consumed.

the hand and neighborhood industries have been excluded. The census for 1919, and the earlier censuses, included all establishments with annual products valued at $500 or more; after 1919 the lower limit was $5,000. As data for 1899 are available both with and without the inclusion of the hand and neighborhood industries, and for 1919 both with and without establishments with products valued under $5,000, we may divide the entire period into three segments for close comparisons, namely:

1. 1869–1899, with data covering both factory and hand and neighborhood industries, for establishments with annual product valued at not less than $500.

2. 1899–1919, with data covering factory industries only, for establishments with annual product valued at not less than $500.

3. 1919–1929, with data covering factory industries only, for establishments with annual product valued at not less than $5,000.

These three periods have been observed in compiling Table 15. Various minor adjustments (indicated in the footnotes to Table 15), some of which are necessarily estimates,[4]

[4] Some additional causes of discrepancy have not been eliminated. While these do not, we believe, seriously impair the usefulness of the data, it may be well to note them. In the censuses of 1869 and 1879, the inquiry called for 'hands employed', and it may be that some workers other than wage earners were included, though the Census Bureau has stated that it does not believe salaried employees were as a rule included. In 1889 employees were separately designated as (1) officers, firm members and clerks; (2) operatives, skilled and unskilled, and piece workers. The data used for 'wage earners' exclude the first group. In all subsequent censuses 'wage earners' have been separately reported as such. Furthermore, in the census of 1899 and subsequently "the average number of wage earners for the year was computed by adding the numbers reported for the several months and dividing the sum by twelve. . . . If a factory employed, say, a hundred wage earners, but was in operation only six months during the year, the method of calculation would show an average of 50 wage earners employed for the year. At the census of 1889 and possibly for prior censuses, such a

have been made in order to render the data for the several censuses in each of the three periods comparable for the period. The scope of the power census has also varied somewhat with respect to equipment covered, being restricted to steam and water power only in 1869 and 1879. Some later discrepancies have been ironed out in the preparation of Table 14. The proportion of the hand and neighborhood industries increased in the census of 1889, largely owing to greater care in canvassing this group. The ratio of power to wage earners was probably lowered thereby but no attempt has been made to correct for this bias.

The changing significance of rated horsepower

During the last two decades a rapid increase has occurred in the use of purchased electric power (Table 24). In 1909 electric motors driven by purchased electric power represented only 9 per cent of the rated capacity of manufacturing plants; in 1919, 32 per cent; in 1929, 53 per cent. Dr. Willard Thorp points out that this marked increase in the use of electric power has changed the significance of rated power.[5] When power is produced by steam or water-power engines or turbines in the reporting establishment, even if delivered to dynamos and transformed to electric power, the rated capacity given in the *Census of Manufactures* is the rated capacity of the steam or water-power prime movers rather than that of the electric motors driven by the current generated in the plant; but when current is purchased from the outside, rated capacity refers to the rated capacity of the electric motors. Now, there are essential differences between the rated capacity of steam or water-power prime movers

factory would have been counted as employing 100 wage earners." *Thirteenth Census of the United States,* VIII, 20.

[5] Ref. 21, pp. 379-85.

and the rated capacity of electric motors driven by current generated by these prime movers.

In the first place, the rated capacity of steam and water-power engines and turbines "is generally the maximum load which they can carry". On the other hand, it is possible to run electric motors for short periods at considerably more than rated capacity.

Second, improvements in the transmission of power, chiefly by the substitution of electric power transmission within the plant for the old belt-and-shaft method, tend to reduce the primary power required to accomplish a given amount of work.

Third, when electric motors are driven by current generated in the establishment the rated capacity of the motors is likely to exceed considerably the rated capacity of the prime movers, because all motors in the establishment do not run at the same time or at full capacity. Likewise, when purchased electric current is substituted for water-power or steam prime movers the rated horsepower of the plant, in this case based on the electric motors, is likely to show an increase even though no change is made in the work done. In a subsequent section on the growth of electrification, we have used, as a rough approximation, an estimate that 100 horsepower of electric motors in factories require prime movers with rated capacity of 72 horsepower (Table 24).

Thus, with the increasing use of electric power, two factors—the possibility of running motors with an overload and the improvements in transmission of the individual-motor drive over the mechanical belt-and-shaft system—tend to lower the required capacity without changing the amount of work that can be accomplished. Another factor, probably more important than the first two, tends to increase rated capacity without a corresponding change in work done. No accurate balance can be struck between these factors, but it

should be recognized that they limit the comparability of the statistics of horsepower.

Rated capacity, even if consistently measured, may be a variable index of the actual use of power. In some ways a better index of mechanization would be power used in terms of kilowatt-hours or their equivalent.

Power an inadequate measure of mechanization

While the increase in the use of power in industry is doubtless a fair, rough indicator of increasing mechanization, it is clearly not a precise measure. What we need to measure is not rated capacity or even the quantity of energy the machine employs, but rather its producing capacity and its effect on the quantity and quality of attending labor required. For example, in the glass industry the sheet machine and the cylinder machine vary much more in skill displacement than in horsepower employed. It requires little or no more power to draw up a sheet of glass with the sheet machine, and yet the sheet is ready for cutting, while the cylinder must be flattened by skilled flatteners. Likewise the high speed warper in cotton spinning mills, operating as it does under a lighter tension than the old-style warper, probably requires less power, but through its greater speed makes a substantial reduction in the labor required (see Ch. III). A conveying system, utilizing chutes and gravity roller-bearing sections, may require little or no power and yet represent substantial replacement of manual labor by equipment. Doubtless in numerous instances the increase in power used or in rated horsepower is not commensurate with the actual increase in the use and effectiveness of mechanical equipment. That horsepower per worker is not always an adequate index of the degree of mechanization is suggested by consideration of the typical cotton goods factory. A cotton mill

is filled with whirring machinery, and our sample indicates that a large proportion (over four-fifths) of cotton mill workers are engaged in tending machines or in work auxiliary to their operation. Yet in 1929 the horsepower per worker in cotton goods was only 5.28 as compared with 8.41 in butter and cheese, 13.14 in the sugar industry, and 33.47 in the manufacture of ice. Such apparent inconsistencies arise in part from the large amount of power required by industries that work heavy materials and also from the use of power for refrigerating and other processing as well as for driving machinery.

PROPORTION OF ESTABLISHMENTS USING POWER [6]

The changes in the proportion of manufacturing establishments reporting the use of power affords some indication of the extension of power manufacturing. Only about one-third of the total number of establishments reported power in the censuses of 1879, 1889 and 1899 (Table 14). However, the early censuses included various hand and neighborhood industries, and when these are excluded from the census of 1899 the percentage of power-reporting establishments rises to 64. By 1919 the percentage had risen to 82 (86 when the small plants with value of product under $5,000 are excluded), and by 1929, 92 per cent of all manufacturing establishments reported the use of power.

[6] As used in the *Census of Manufactures*, the term 'establishment' usually signifies a single plant or factory. "In some cases, however, it refers to two or more plants operated under a common ownership and located in the same city, or in the same county but in different municipalities or unincorporated places having fewer than 10,000 inhabitants. On the other hand, separate reports are occasionally obtained for different industries carried on in the same plant, in which event a single plant is counted as two or more establishments" (*1929*, I, 3).

TABLE 14

PROPORTION OF MANUFACTURING ESTABLISHMENTS REPORTING POWER, AND AVERAGE HORSEPOWER PER ESTABLISHMENT [1]

CENSUS YEAR	TOTAL NUMBER	NUMBER REPORTING POWER	PERCENTAGE REPORTING POWER	HORSEPOWER PER ESTABLISHMENT REPORTING POWER [2]
Hand and neighborhood industries included				
1879	253,852	85,923	33.8	41.4
1889	321,584	98,943	30.8	59.2
1899	470,005	157,862	33.6	67.6
Factory industries only, with product $500 or more				
1899	207,514	133,418	64.3	74.5
1904	216,180	134,481	62.2	100.3
1909	268,491	185,042	68.9	100.9
1914	275,791	205,590	74.5	109.1
1919	290,105	237,854	82.0	124.0
Factory industries, with product $5,000 or more				
1919	214,188	184,225	86.0	158.5
1923	196,182	173,415	88.4	190.8
1925	187,981	168,282	89.5	212.8
1927	191,866	174,118	90.7	223.0
1929	210,474	193,603	92.0	221.7

[1] Compiled from the *Census of Manufactures* in the United States. A few industries have been eliminated in order to increase the comparability among the census periods. The 1899 data are given first with hand and neighborhood industries included, for comparison with 1879 and 1889, and then with these industries excluded, for comparison with 1904 and subsequent periods. Likewise the 1919 data are given first for establishments with product valued at $500 or more, for comparison with previous censuses, and then for establishments with value of product of $5000 or more, for comparison with subsequent censuses. In arriving at the revised 1919 figures, it was estimated that of 65,485 establishments with products valued at less than $5000, the number reporting power was 43,000.

[2] The total horsepower data are in Table 15.

It is probable that some irregularities in the changes shown

in Table 14 are due to greater efforts at some censuses to cover the smaller establishments, to incomplete reporting of power, and to the impossibility of a perfect adjustment for changes in the scope of the census in 1904 and 1919.

The change in scope in 1904 and 1919 brought sharp declines in the number of manufacturing establishments. But even in the period 1919–29—with no major changes in scope—the number declined from 214,188 to 210,474.

Meanwhile, the horsepower per establishment reporting power increased rapidly—from 41 in 1879 to 67 in 1899 (75 after excluding the neighborhood industries), to 124 in 1919 (159 if establishments with value of product less than $5,000 are excluded), and by 1929 to 222 horsepower per establishment. Doubtless the elimination of many small plants, the expansion of existing plants and the transition from hand to machine work without an equivalent plant expansion, have all contributed to the marked increase in horsepower per establishment in the half century covered by Table 14.

INCREASE IN TOTAL HORSEPOWER

Since the Civil War there has been a continuous increase in the installed capacity of primary horsepower in manufacturing, both in the aggregate and in terms of horsepower per worker. The data for each census period are summarized in Table 15. To lessen the degree of non-comparability arising from changes in scope previously described the statistics are presented in three period groups. For Group A (1869–99) the data cover the hand and neighborhood industries as well as factories whose annual value of product is $500 or more; for Group B (1899–1919) they pertain to factories only, with value of product $500 or more; for Group C (1919–29) only factories with an annual product valued at $5,000 or more are included. The index numbers are chained

TABLE 15

INCREASE IN RATED HORSEPOWER CAPACITY IN MANUFACTURING[1]

CENSUS YEAR	WAGE EARNERS (THOUSANDS)	TOTAL HORSEPOWER (THOUSANDS)	HORSEPOWER PER WAGE EARNER	INDEX NUMBERS 1919=100: WAGE EARNERS	INDEX NUMBERS 1919=100: TOTAL HORSEPOWER	INDEX NUMBERS 1919=100: HORSEPOWER PER WAGE EARNER	GEOMETRIC MEAN RATE OF GROWTH PER YEAR SINCE PRECEDING CENSUS: TOTAL HORSEPOWER (PER CENT)	GEOMETRIC MEAN RATE OF GROWTH PER YEAR SINCE PRECEDING CENSUS: HORSEPOWER PER WAGE EARNER (PER CENT)
Group A Hand, neighborhood and factory industries								
1869	2,028	2,314	1.14	20.2	7.3	36.2	...	...
1879	2,772	3,560	1.28	27.6	11.2	40.6	4.4	1.2
1889	4,171	5,857	1.40	41.5	18.5	44.4	5.1	0.9
1899	5,209	10,670	2.05	51.8	33.7	65.1	6.2	3.9
Group B Factories with $500 or more product								
1899	4,713	9,942	2.11	51.8	33.7	65.1	...	...
1904	5,468	13,488	2.47	60.1	45.7	76.2	6.3	3.2
1909	6,615	18,675	2.82	72.7	63.3	87.0	6.7	2.7
1914	7,036	22,437	3.19	77.4	76.0	98.5	3.7	2.5
1919	9,096	29,505	3.24	100.0	100.0	100.0	5.6	0.3
Group C Factories with $5,000 or more product								
1919	8,998	29,209	3.25	100.0	100.0	100.0	...	...
1923	8,777	33,092	3.77	97.5	113.3	116.0	3.2	3.8
1925	8,390	35,807	4.27	93.2	122.6	131.4	4.0	6.4
1927	8,350	38,826	4.65	92.8	132.9	143.1	4.1	4.4
1929	8,831	42,918	4.86	98.1	146.9	149.5	5.1	2.2

[1] Compiled from the *Census of Manufactures*, with adjustments to make the data within each group as comparable as possible, namely: lead pig, quartz milled, and raw cane and sorghum sugar and molasses were subtracted from the original census figures for 1869; in 1879 additions were made for wage earners and horsepower in petroleum refining, for estimates by the writer of wage earners in bottling, gas, and car repairing, and esti-

mates (by W. L. Thorp, Ref. 21) for horsepower in bottling, gas, car repairing, coke, dyeing and finishing textiles, distilled liquors, malt liquors, shipbuilding and glass. Electric light and power was subtracted from data for 1879 and 1889. Druggists' preparations, dressmaking, cotton ginning, and millinery custom work were subtracted from both 1889 and 1899, and trimming and finishing coffins and burial cases, hay and straw bailing, teasels, and mechanical dentistry from 1889. The 1899 horsepower figure was corrected by subtracting 311,016 horsepower of electric motors, and, when used in Group B, a further correction of 157,125 for industries included in the original census in 1899 but not in 1904. For Group C, poultry killing and dressing was excluded from 1919, 1923, 1925 and 1927; and an estimate for coffee and spice grinding and roasting added to 1925. Data for 1919 were also corrected by excluding automobile repairing, purchased power other than electricity (94,432 horsepower), an arbitrary sum of 15,000 for water motors, and 41,251 wage earners and 100,000 horsepower (estimate) for plants with less than $5,000 value of product.

together at the transition points so as to make them as comparable as possible from 1869 to 1929.

RATE OF INCREASE

In which period has the rate of mechanization been fastest? The apparent answer is afforded by the geometric rates of increase in the last two columns of Table 15, computed for the interval between each census date. The annual increase in total horsepower was greatest in the five-year period 1904–09, and least in the post-War period. However, for horsepower per wage earner the showing is quite different. In no period since 1900 has the rate of increase been as great as in any one of the post-War periods other than 1927–29, the most rapid gain being from 1923 to 1925, or 6.4 per cent per year.

To some extent this rate of increase must be discounted to allow for the increasing use of purchased electric power discussed above. Allowing, however, for the respects in which rated horsepower does not furnish a complete account of the

tendency in the use of machinery, it still seems reasonable to interpret the data for horsepower in manufacturing as indicating a relatively rapid mechanization since the World War.[7]

INCREASES IN POWER EQUIPMENT PER WAGE EARNER, BY INDUSTRIES

Appendix C gives the horsepower per worker ratios for each of 141 individual industries or industrial groups at each census from 1899 to 1929. For 100 of the individual industries and for the industrial groups we also computed the percentage increase in the horsepower ratio from 1899 to 1925. These ratios of increase for the major industrial groups, and also for the 10 industries having the smallest increases and the 10 having the largest percentage increases, are presented in Table 16.

TABLE 16

PERCENTAGE INCREASES IN HORSEPOWER PER WAGE EARNER, MANUFACTURING INDUSTRIES: 1899–1929 [1]

GROUP	PERCENTAGE INCREASE
A. Major industrial groups	
Food and kindred products	22.6
Lumber and its remanufactures	39.4
Textiles and their products	78.7
Paper and printing	110.8
Leather and its finished products	114.1
All industries combined	130.3
Iron and steel and their products	157.8
Rubber products	183.1
Miscellaneous industries	220.5
Tobacco manufactures	229.4
Non-ferrous metals and their products	257.9

[7] It is suggested by Colonel M. C. Rorty that each successive increase in horsepower per worker may (and perhaps should) show a decreasing rate of increase in productive efficiency.

TABLE 16 *(cont.)*

PERCENTAGE INCREASES IN HORSEPOWER PER WAGE EARNER, MANUFACTURING INDUSTRIES: 1899–1929

GROUP	PERCENTAGE INCREASE
Chemicals and allied products	276.1
Stone, clay and glass products	299.5
Vehicles for land transportation, including railroad repair shops	317.7
B. Ten individual manufacturing industries with smallest percentage gains	
Wire	7.6
Flour-mill and grain-mill products	13.9
Paper and wood pulp	15.1
Butter and cheese	22.2
Sugar, beet and cane	26.7
Knit goods	27.9
Fancy articles	28.3
Boots and shoes, rubber	40.2
Lumber and timber products, n.e.c.	42.3
Shirts	47.4
C. Ten individual manufacturing industries with largest percentage gains	
Bread and other bakery products	378.3
Steam fittings and steam and hot water heating apparatus	395.7
Glass	406.0
Steam railroad repair shops	430.9
Confectionery, chewing gum, and ice cream	456.9
Carriages and wagons	483.1
Structural and ornamental iron work	512.7
Gas, manufactured, illuminating and heating	795.7
Coke	833.2
Cigars and cigarettes	1,075.0

[1] Computed from ratios of horsepower to wage earners given in Appendix C. N.e.c.=not elsewhere classified.

In the three decades 1899–1929, none of the industries listed in Table 16 declined in horsepower per worker, though the gain was relatively slight for the food and lumber groups and for several constituents of these groups. The individual

industries range from a 7.6 per cent increase for wire to a 1075 per cent increase for cigars and cigarettes. The median increase for the 100 individual industries listed in Appendix C is 158 per cent, and about half show an increase of between 100 and 250 per cent. Doubtless some of the observed peculiarities in the ranking may be due to inadequacies of the data, especially for 1899, and to changes in classification not fully allowed for.

Another picture of the upward drift in horsepower per wage earner is afforded by Table 17, which portrays the

TABLE 17

FREQUENCY DISTRIBUTIONS OF NINETY-NINE INDUSTRIES, BY HORSEPOWER PER WAGE EARNER, CENSUS PERIODS: 1899–1929[1]

HORSEPOWER PER WAGE EARNER	1899	1904	1909	1914	1919		1923	1925	1927	1929
					UNADJUSTED	ADJUSTED[2]				
0– .99	52	45	35	31	26	26	19	18	18	17
1.00–1.99	22	25	30	27	32	32	28	22	20	20
2.00–2.99	10	11	11	15	13	13	16	16	17	15
3.00–3.99	5	7	11	6	6	7	12	12	12	14
4.00–4.99	2	1	2	7	8	6	5	10	9	8
5.00–5.99	1	2	1	3	3	5	6	4	4	5
6.00–6.99	2	1	3	1	4	3	2	4	3	3
7.00–7.99	..	3	..	2	2	2	1	2	4	2
8.00–8.99	1	..	1	1	1	1	2	1	1	2
9.00–9.99	..	..	..	2	..	..	2	2	1	2
10.00 or more	4	4	5	4	4	4	6	8	10	11

[1] Computed from data in Appendix C.

[2] The 1919 'unadjusted' figures cover plants with value of product $500 or more, and include rented power other than electric; the 1919 'adjusted' figures cover plants with value of product $5,000 or more, and exclude rented power other than electric. The 'unadjusted' figures are comparable with those for the earlier censuses; the 'adjusted', with the subsequent censuses.

frequency distributions of horsepower per worker for those industries for which data are available at each census from

1899 to 1929. That the shift towards increasing horsepower per wage earner from census to census has been more or less common to the individual industries will be evident from an examination of the several distributions in Table 17. Though the modal class remains at 0 to 0.99 horsepower per wage earner from 1899 to 1914, inclusive, it is evident from the successive distributions in Table 17 that even in this period the zone of concentration is gradually shifting towards the higher ratios of horsepower per wage earner. In 1919, despite the fact that, with a large increase in the number of wage earners, horsepower per wage earner declined in many industries, the center of concentration has shifted sufficiently to bring the modal class into the 1.00–1.99 group, and thereafter the concentration becomes increasingly less, as numerous industries move into the upper ratio ranges. In fact, an examination of the detail in Appendix C will reveal that of the 934 year-to-year changes in horsepower per worker there recorded for individual industries, only 184 are declines. The rate of progress in the several industries has varied, but most have grown in mechanization in each census period.

POWER IN THE NON-MANUFACTURING INDUSTRIES

The detail in which data are available has enabled us to discuss at length the growth of power in manufacturing. However, it must not be inferred that growth has been restricted to manufacturing. It has been at least as great in other industries. Estimates for all but a few of the industries making extensive use of power have been compiled by Mr. Carroll R. Daugherty for the decennial census years beginning in 1849, also for 1923.[8] These estimates of the total

[8] See references cited in footnotes to Table 18.

horsepower available in other industries, for 1899, 1909, 1919 and 1929, together with horsepower data compiled from the *Census of Manufactures,* are recapitulated in Table 18.

TABLE 18

ESTIMATED RATED CAPACITY OF POWER EQUIPMENT IN SELECTED INDUSTRIES: 1899–1929 [1]

(unit: 1,000 horsepower)

INDUSTRY	*1899*	*1909*	*1919*	*1929*
Total, prime movers [2]	64,081	112,856	176,143	401,000
Prime movers and motors run by purchased power [3]				
'Productive' automobiles	[4]	256	10,964	162,483
Steam railroads	20,900	45,400	72,300	109,331
Agriculture	23,519	31,107	43,722	69,639
Electric central stations	1,200	5,225	15,250	43,000
Manufacturing	9,942	18,675	29,209	42,918
Mines and quarries	2,868	4,609	6,723	10,500
Ships	1,819	3,155	6,402	9,017
Electric railroads	1,079	3,718	6,327	8,550
Work animals not on farms	3,055	3,405	1,979	1,400
Irrigation and drainage	120	361	816	1,383

[1] Data for manufacturing from Table 15; for other industries, from Carroll R. Daugherty, Horsepower Equipment in the United States, 1869–1929, *American Economic Review,* September 1933, pp. 428–40, especially p. 434; see also Ref. 31.

[2] Prime movers include steam engines and turbines, internal combustion engines, water wheels, wind power and work animals, but not electric motors run by purchased current. Pleasure automobiles are excluded. The total for prime movers includes those installed in all the industries listed in Table 18 and also 3,091,000 horsepower in commercial aircraft in 1929.

[3] There is some duplication in these figures in that a portion of the current generated by central electric stations is used to operate motors installed in manufactures, mines and quarries, agriculture, irrigation and drainage and electric railroads. Also, auto trucks are included under both agriculture and 'productive' automobiles.

[4] No data available.

Both agriculture and steam railroads were more extensive users of power than manufacturing at each of the four dates for which estimates are recorded in Table 18. Also, by 1929 the rated horsepower of 'productive' or non-pleasure automobiles, as estimated by Daugherty, exceeded the rated capacity of power equipment in any one of the three fields: agriculture, railroads or manufacture.

To some extent the interpretation of the increase in the use of power by the non-manufacturing industries is clouded by the fact, previously noted in connection with power in manufacturing, that there has been an increasing use of electric motors driven by purchased power, and this increase is not necessarily accompanied by an equivalent increase in the total equipment driven by power.[9]

In some industries the observed increases in the total horsepower available arise in part from the expansion of the industry as well as from increasing mechanization; but that increases in mechanization have been very substantial is indicated by the estimates in Table 19 of horsepower per worker for four major industries in 1909, 1919 and 1929.

In manufacturing the horsepower per worker increased 15 per cent from 1909 to 1919, and nearly 50 per cent in the following decade. In steam railroads, the increase per employee was about 25 per cent from 1909 to 1919 and nearly three times as great in the period 1919–29. In agriculture

[9] The percentages of available horsepower equipment actuated by purchased electric power are estimated by Daugherty as follows (Ref. 31, pp. 49–51):

	1909	*1919*	*1923*
Manufactures	9.4	31.7	40.4
Mines and quarries	4.5	23.9	33.3
Electric railroads	16.9	31.1	39.6
Agriculture	0.8	3.4	4.6

TABLE 19

HORSEPOWER PER WORKER IN SELECTED INDUSTRIES: 1909–1929

INDUSTRY	HORSEPOWER PER WORKER			PERCENTAGE INCREASE	
	1909	*1919*	*1929*	*1909–19*	*1919–29*
Manufactures [1]	2.82	3.25	4.86	14.9[5]	49.5
Agriculture [2]	2.51	4.10	6.65	63.3	62.2
Mines and quarries [3]	3.64	5.52	8.85	51.6	60.3
Steam railroads [4]	30.21	37.79	65.82	25.1	74.2

[1] From Table 15.

[2] Horsepower per person in agricultural pursuits as given in *Census of Occupations, 1930;* power data from Table 18.

[3] Horsepower per wage earner in mining, exclusive of petroleum and natural gas and sand and gravel (*Census of Mines and Quarries, 1929*).

[4] Horsepower per employee; power data from Table 18; number of employees from Interstate Commerce Commission, *Statistics of Railways*. The data for 1909 cover employees of all operating railroads, except switching and terminal companies, for year ending June 30, 1909; for 1919 and 1929 they cover employees on Class I railroads (except switching and terminal companies), in calendar years.

[5] In computing percentage change, 1909–19, horsepower per worker in 1919 is taken as 3.24 (see Table 15).

and mining the increase exceeded 50 per cent in both decades. These estimates are not strictly comparable in all respects, but we do not believe that strictly comparable records would make an essentially different showing.[10]

It is unnecessary to recount here in detail the many changes which in the aggregate account for the marked increases in the use of power in the non-manufacturing industries, but a few major developments may appropriately be mentioned.[11] Of the total rated horsepower of mine equipment in 1929, over a third was of the mobile type. In some part this is a reflection of the continued expansion of mechanical undercutting and mechanical transportation, and in

[10] For elements of non-comparability, in addition to the increasing use of electric motors run by purchased power, see footnotes to Table 19.

[11] See Ch. IV and V for further detail.

part of the start made in the development of mechanical loading in the decade of the 'twenties. The major portion of the increased use of power on farms consists in mechanical power furnished by tractors and motor trucks. The number of tractors on farms increased from 246,083 in 1920 to 920,021 in 1930, or nearly fourfold. The number of motor trucks on farms increased from 139,169 to 900,385, and in the same period there were large sales of stationary gas engines and a substantial increase in the use of electricity on the farm.[12] The marked increase in horsepower per worker in steam railroads is caused mainly by an increase in the average tractive power of locomotives from 35,789 pounds in 1919 to 44,801 in 1929, in conjunction with a decline in the number of railroad employees.

Other Measures of Changing Mechanization

Because the statistics on horsepower, though available in considerable detail, do not give an entirely adequate picture of the developments in mechanization, it is pertinent for us to examine other measures of the extent to which industry is becoming more completely mechanized.

RATIO OF WAGES TO VALUE ADDED BY MANUFACTURE

The more highly mechanized a plant is, the greater the proportionate expenditure for maintenance and repair, materials, power and such items of overhead as interest; hence it would seem a reasonable presumption that with increasing mechanization a smaller proportion of total expenditures will

[12] Indicated by the fact that in 1920 only 452,620 farm dwellings were lighted by electricity while by 1930 the number had risen to 841,310. The *1930 Census of Agriculture* shows 386,191 electric motors and over a million stationary gas engines in use on farms.

go for wages. If this be true, the ratio of wages to value added by manufacture should afford a supplementary measure of changing mechanization.[13] In fact, however, the changes in the ratio of wages to value added, presented in Table 20 for the period 1869–1929, do not appear to be a sensitive meas-

TABLE 20

RATIO OF WAGES PAID TO VALUE ADDED BY MANUFACTURE: 1869–1929 [1]

CENSUS YEAR AND SCOPE OF CENSUS	RATIO (PER CENT)
Hand and neighborhood industries and factories, with $500 or more product	
1869	44.5
1879	48.1
1889	44.9
1899	41.0
Factories only, with $500 or more product	
1899	41.6
1904	41.5
1909	40.2
1914	41.3
1919	42.1
Factories only, with $5,000 or more product	
1919	42.2
1921	44.7
1923	42.6
1925	40.1
1927	39.3
1929	36.4

[1] Computed from statistics of total wages paid and value added by manufacture in *1919 Census of Manufactures*, p. 14; *1927*, p. 16, and *1929*, I, 15.

[13] As used in the *Census of Manufactures* 'value added' is the increment created by the manufacturing process and "is calculated by deducting the cost of materials, containers, fuel, and purchased electric energy used from the value of the products" (1929, I, 8).

ure for the changes in mechanization, at least not of their long-time trend. The wage ratio was 44.5 in 1869, 41.6 in 1899, and 42.6 as late as 1923. Evidently other factors, such as differences in the movement of wage rates and unit prices of manufactured products have acted to conceal the effect of mechanization upon the wage ratio.[14] However, the ratios for 1927 and 1929 show appreciable declines; and that the wage ratio is correlated with changing mechanization is supported by a closer examination of the data by industries in the period 1923–25. If we may trust our horsepower data and other evidence, these two years were characterized by rapid mechanization, and we find not only that the wage ratio for all industries declines from 42.6 to 40.1, but also that this decline is common to all the sixteen major industrial divisions of manufacturing except lumber. Moreover, when we examine the 347 individual industries for which the wage ratio can be computed for both 1923 and 1925, we find that 221 decline from 1923 to 1925.

It is evident that the wage ratio is influenced by mechanization but cannot be relied upon for precise evidence concerning the rate at which mechanization has advanced in various periods.

[14] Colonel M. C. Rorty comments: There is some evidence, notably that afforded by the increasing rates of obsolescence and replacement for machine tools (charges on this account being to expense, rather than for use of capital), to support the hypothesis that, the more highly mechanized an industry becomes, the lower may be the proportion of its value added that accrues to capital. A particular effort of the highly organized and mechanized industries is to increase their rates of capital turnover, i.e., the ratio of gross output to capital employed. Furthermore, in many cases, the highly elaborated machine costs less than the crude machine per dollar of annual output. It should be noted, also, that the ratio of wages to value added was so seriously affected, during the 1920–29 period, by the readjustment of real corporation interest and dividends to normal levels at the end of 1928 (after a previous 33 1/3 per cent decline) that any effects of mechanization must have been obscured.

PROPORTION PRODUCED BY MACHINE METHODS

One measure of mechanization that is quite significant, though ordinarily not obtainable, is the proportion of output that is prepared by machine methods rather than hand methods in specific phases of producing operations. Such data are available for the undercutting and loading processes in coal mining and for a few manufacturing processes such as the casting process in pig iron production (Appendix A). They furnish realistic measures of changing mechanization—measures the meaning of which can be readily interpreted—and it is unfortunate that similar data are not available for a large number of important manufacturing processes.

The United States Geological Survey compiles figures of the proportion of soft coal which is 'machine mined', that is, undercut by machine. Similar data are presented for anthracite coal. The detailed statistics for recent years appear in Table 40. The proportion of bituminous coal undercut by machine has increased steadily from only 5.3 per cent in 1891 to 24.9 per cent in 1900, 41.7 per cent in 1910, 59.8 per cent in 1920, and 75.4 per cent in 1929. The percentage of anthracite coal undercut by machine is relatively small, between 1 and 2 per cent.

Machine undercutting has probably about reached the saturation point, but machine loading is apparently still in its infancy. The proportion of bituminous coal loaded with self-feeding loading devices, while yet small, has shown a substantial increase from only 0.3 per cent in 1923 to 3.6 per cent in 1929 (Table 40).

In pig iron production the percentage of total merchant furnace output that is machine cast increased from 45 in 1911 to 85 in 1926, but was as low as 31 in 1915 (Table 36).

Machine-made cigars constituted less than 10 per cent of

the total prior to 1924, but by 1930 about 47 per cent of long-filler cigars were machine-made (Table 38).

Likewise, the rapid advance of the automatic glass bottle machine is indicated by the estimate that in 1917 only 50 per cent of glass jars and bottles were blown on automatics; in 1924, 90 per cent [15] (Table 38).

PROPORTION OF USERS EQUIPPED WITH SPECIFIED DEVICE

Closely akin to statistics of the proportion of output produced by machine methods are statistics of the proportion of users equipped with a given device. The best illustration of this method of charting the progress of mechanization is afforded by estimates of the percentage of wired homes equipped with various labor-saving devices (Appendix A). It is estimated that from 1924 to 1930 the percentage equipped with ironing machines rose from 1.6 to 3.3, with electric irons, from 77.0 to 97.8, with electric vacuum cleaners, from 37.7 to 44.4, and with electric washing machines, from 26.4 to 35.1.

Somewhat similar data are available for the telephone industry. In 1919 only 1.7 per cent of the total number of Bell-owned stations were served by automatic switchboards. By 1929 this percentage had risen to 26.0.

PROPORTION OF NEW EQUIPMENT THAT IS POWER-DRIVEN

Another closely allied measure of changing mechanization is afforded by statistics of the proportion of new equipment that is operated by mechanical power. Thus one of the significant movements in the mechanization of agriculture is indicated by the rapid rise in the ratio of the value of

[15] See Ch. III, Glass, which also gives an estimate for the percentage of window glass made by the hand process.

harvesting combines (all power-driven) to the total value of harvesting machinery sold—from only 11.7 per cent in 1920 to 33.2 per cent in 1926, and 51.9 per cent in 1929.[16]

NUMBER OF MACHINES IN USE

Another indicator of mechanization is afforded by statistics of the number of machines of a given type in use, although this measure does not give directly a mechanization ratio. It merely measures progress in absolute numbers; it does not indicate whether the given procedure is gaining ground relatively to hand methods or less mechanized equipment.

In this class of evidence concerning the advance of mechanization we may include such items as the following. The registration of motor trucks has increased from only 85,600 in 1914 to 1,006,082 in 1920, and 3,379,854 in 1929. In 1924 the number of tractors on farms was reported as 505,933; in 1929 as 920,000. The number of semiautomatic glass blowing machines in use declined from 459 in 1916 to only 26 in 1927, yielding to the advance of the full automatic type. The number of Bell-owned stations served by automatic switchboard increased from only 130,000 in 1919 to 4,014,000 in 1929. The estimated number of electric washing machines in use rose from 3,500,000 in 1924 to 7,185,000 in 1930. The number of undercutting machines in bituminous coal mining was reported as 16,507 in 1914; it increased to 21,299 in 1923, but has not held its own since. The decline (to 14,731 in 1929) has been offset by an increasing production per machine. These and other illustrations of measuring the growth of mechanization by changes in the number of equipment units of a given type in use

[16] For further statistics of this type, see Table 6.

appear in Chapters III, IV and V and in the tables in Appendix A.

Growth of the Machine-producing Industries

With the growth in mechanization indicated by the other indexes examined, have the machinery industries outstripped the other manufacturing industries? By referring to the data in Table 21 we note that from 1899 to 1929 the

TABLE 21

GROWTH OF THE MACHINE-PRODUCING INDUSTRIES[1] (EXCLUSIVE OF TRANSPORTATION EQUIPMENT)

Thousands of Wage Earners

INDUSTRY	*1899*	*1904*	*1909*	*1914*	*1919*	*1921*	*1923*	*1925*	*1927*	*1929*
Total, machinery industries[2]	414	478	568	615	998	662	908	859	886	1,091
Percentage ratio to wage earners in all manufacturing industries	8.8	8.7	8.6	8.7	11.0	9.5	10.3	10.2	10.6	12.4
Foundry and machine-shop products, n.e.c.[3]	297	332	379	358	483	321	449	398	398	454
Electrical machinery, apparatus and supplies	42	60	87	118	212	161	235	240	242	329
Engines, turbines, and water wheels	[4]	[4]	[4]	30	78	36	48	51	54	61
Machine tools	[4]	[4]	[4]	[4]	53	21	33	31	35	47
Agricultural implements	47	47	51	48	54	30	31	29	33	42
Textile machinery and parts	[4]	[4]	[4]	[4]	32	31	36	28	26	27
Pumps (hand and power) and pumping equipment	1	1	2	8	16	12	15	18	19	23
Typewriters and supplies	4	6	10	11	16	13	15	15	17	17

TABLE 21 (*cont.*)

GROWTH OF THE MACHINE-PRODUCING INDUSTRIES[1]
(EXCLUSIVE OF TRANSPORTATION EQUIPMENT)

Thousands of Wage Earners

INDUSTRY	*1899*	*1904*	*1909*	*1914*	*1919*	*1921*	*1923*	*1925*	*1927*	*1929*
Cash registers, adding machines, and calculating machines	2	4	7	9	17	10	15	13	14	17
Sewing machines, cases, and attachments	13	17	19	18	19	13	13	12	12	10
Refrigerators, mechanical	5	5	5	5	5	5	5	5	11	17
Washing machines, wringers, driers, and ironing machines for household use	2	2	2	2	6	4	6	7	8	8
Metal-working machinery, other than machine tools	4	4	4	4	4	4	4	6	6	4
Gas machines and gas and water meters	2	3	5	5	6	4	6	6	6	6
Scales and balances	3	3	4	4	5	4	4	4	4	4
Windmills and windmill towers	2	2	2	2	2	1	1	1	1	2

[1] Compiled from the *Census of Manufactures* for the several censuses, 1899–1929.

[2] The totals were computed from the original figures before they were reduced to thousands.

[3] The following industries included in the earlier censuses in 'Foundry and machine-shop products' have been excluded by us, partly by estimate: Locomotives and stoves and furnaces in 1899; cast iron pipe, 1899 and 1904; automobile repairing, 1904 and 1909; steel barrels, drums, and tanks, and tempering and welding of iron and steel, 1899 to 1914.

[4] Included in 'Foundry and machine-shop products' at the census periods for which these industries are not separately listed in this table.

[5] Prior to 1927 included in 'Electrical machinery' or 'Foundry and machine-shop products'.

number of wage earners in the machine-producing industries, exclusive of transportation equipment, increased from 414,000 to 1,091,000, or from 8.8 to 12.4 per cent of the total number of wage earners in manufacturing. The nearly one million wage earners in the machinery industries in 1919 represents the high point previous to 1929 both in absolute numbers and in percentage of the total number of wage earners in manufacturing.

The majority of the machine-producing industries are included under the designation 'Foundry and machine-shop products not elsewhere classified'. From this parent group one special machinery industry after another has been separated at the successive censuses. To maintain comparability both the parent group of 'Foundry and machine-shop products' and the several separately classified machinery industries are included in the totals for the machinery industries in Table 21. The nature of the 'Foundry and machine-shop' group is indicated by the following quotation from the *1927 Census of Manufactures:*

> "This industry. . . . embraces the manufacture of those products of boiler shops, foundries, and machine shops which are not assigned to special classifications. The foundry, as the term is ordinarily defined, is an establishment in which metal is cast into various shapes, and the machine shop is an establishment in which work is done by means of machine tools; that is, power-driven tools used in cutting and shaping metals. . . . .many foundries and machine shops manufacture a great variety of products." This classification "embraces, so far as practicable, those lines of manufacture which employ foundry and machine-shop processes but which cannot be clearly segregated from one another. Nevertheless, despite its comprehensiveness, a great deal of overlapping occurs between this classification and a number of others" (p. 1,074).

Something of the diversity of the products of the 'Foundry and machine-shop' group is indicated by the fact that in 1914 a "partial list" of the principal products reported on the manufacturer's schedule by establishments assigned to

this industry included 642 items, 402 of which were machines designated for use in the several branches into which the census divides manufacturing, 19 articles each, chiefly machines, for use in mining and agriculture, 70 products intended for use in divers manufactures and 132 intended for general use. Even these last two groups include many types of machine.

For a broad index of the growth of mechanization there is much to be said for the inclusion of the industries grouped by the *Census of Manufactures* under the title 'Transportation Equipment, Air, Land, and Water', or at least that portion of these industries assignable to the production of locomotives and commercial vehicles. For this industry as a whole the number of wage earners in 1921 was 405,773. In 1923 it was 606,328. It declined in 1925 to 559,578, and in 1927 to 494,905, but recovered to 583,355 in 1929. By far the larger proportion of these wage earners is in the two subgroups designated as 'Motor vehicles not including motor cycles' and 'Motor-vehicle bodies and motor-vehicle parts'. The number of wage earners engaged in the production of locomotives and commercial vehicles is not given separately, though a rough estimate might be made from the reported value of these special products. In any event, it is a striking fact that the industries engaged in the production of transportation equipment have employed approximately a half million men in the post-War period, or more than half as many as in the other machine-producing industries combined.[17]

[17] For further discussion of the volume of the machine-producing industries see Ch. VIII.

Measurable Tendencies Contributing to the Progress of Mechanization

Several of the less obvious ways in which mechanization is facilitated are common to so many industries that it is appropriate to call attention to them at this point. We refer to indirect mechanization through the substitution of one process or product for another, the elimination of inefficient plants, regional shifts in industry which involve changes in the average of mechanization and productivity, the increasing capacity of machine units through greater physical size or higher running speeds, the increasing electrification of power equipment, and a group of non-mechanical changes which may conveniently be designated as economies in the use of men and equipment. The latter are not strictly speaking changes in mechanization, but they are significant in studies of changing labor requirements.

Changes indirectly affecting the degree of mechanization

The degree of mechanization in an industry is frequently influenced by changes which do not directly affect the ordinary indexes of mechanization. New industries are constantly arising which, because of their newness and lack of standardization, may have a relatively low degree of mechanization, though the industries which they tend to displace may be applying mechanical devices steadily to more and more operations. Likewise, within any given industry a less mechanized process may partly replace a more mechanized process, or *vice versa,* and thus change the general average of mechanization in the industry as a whole although possibly the degree of mechanization in neither the old nor the new process has undergone any essential change.

For example, an increasing proportion of all bituminous coal mined is by the highly mechanized process of stripping with power shovels.[18] Likewise, the degree of mechanization in pig iron production is raised by the tendency to physical integration of the blast furnace and the steel-making plant, thus virtually eliminating the casting process. The percentage of steel-making pig iron used by makers that is cast in molten condition increased from less than 80 in 1913 to almost 92 by 1931 (Table 36).

In themselves the above illustrations of indirect changes are of relatively minor importance, but the general phenomenon which they illustrate—the growth or decline of mechanization through the substitution of one process or product for another—is an important phase of changing mechanization.

ELIMINATION OF INEFFICIENT PLANTS AND REGIONAL SHIFTS TO HIGH-PRODUCTIVITY AREAS

The rising man-hour productivity of the post-War years is ascribable in part to the elimination of inefficient plants or at least to the shifting of a larger proportion of production to the high-productivity units in the industry. Such changes may raise the level of productivity without necessarily modifying the productivity of individual plants.[19]

The merchant blast furnace industry furnishes a striking example of this tendency, though other developments have

[18] See Appendix A for statistics on the percentages of both bituminous and anthracite coal mined by stripping.

[19] Part of the total gains in productivity are, of course, the result of improvements in individual plants. Examples may be cited from the experience of groups of identical establishments included in our output-per-hour surveys (Ref. 20-c). From 1919 to 1927 productivity per hour increased 34.1 per cent in 5 identical Douglas fir lumber mills, and 46.5 per cent in 5 identical beet sugar plants.

also acted to raise its productivity. Most lakeside plants of the Great Lakes District, for example, "are of the most modern type equipped with complete labor-saving machinery". The plants in New York, Pennsylvania and the South, on the other hand, have a relatively low productivity per man-hour, for various reasons: for example, the "plants in the South are operated mostly by negro labor", and "the plentiful supply of this labor tends to prevent the introduction of improved machinery, thus keeping productivity at a low level". In the period 1917–18 to 1926 there was a "rapid decline of these low productivity areas" and an "increasing production in the high-productivity areas, such as the Great Lakes", which tended to "increase the average productivity of the industry".[20]

Between 1912–14 and 1926 the number of active merchant furnaces had been more than halved, despite the building of new stacks. "The period 1923 to 1926 was featured by the abandonment of old plants in Pennsylvania and the construction of new ones in New York and New England."

In general,

> "one of the most important causes of the great improvement in output per man-hour [in the merchant blast furnace industry] has been the abandonment of many of the inefficient low-productivity plants. In 1921 the average output per man-hour in merchant blast furnaces was very much higher than in the previous year because the depression forced out many of the weaker plants, leaving mostly high-productivity plants in operation. During the prosperity of 1923 many low-productivity plants came back into the industry, but the keener competition of the steel works blast furnaces since then has driven a great number of them out of business. Less than three-fourths of the merchant plants operating in 1923 remained active until 1926, and the high-productivity average of the later year is due in no small degree to the closing down of inefficient plants" (Bul. 474, Ref. 37, p. 1).

Unfortunately, data on causes of changes in productivity

[20] B. L. S., Bul. 474, Ref. 37, notably pp. 9–15.

as adequate as those for the merchant blast furnace industry are not readily available for other industries, but there is considerable reason to believe that in many industries changing mechanization and changing productivity are in substantial part due to the abandonment of inefficient plants and the construction of new more efficient plants, or arise, even when plants are not entirely abandoned, from a greater relative use of the more efficient plants and shifts in the relative volume of production from areas of low productivity to areas of high productivity. We have noted, for example, that even in the localized industry of brick manufacture, the number of establishments has diminished markedly, especially in the smaller, less modernized plants (Ch. III).

An examination of the movement in various industries towards a reduction in the number of establishments tends to confirm the hypothesis that the elimination of relatively inefficient plants is a large factor in increasing mechanization and increasing productivity.

DECLINE IN NUMBER OF MANUFACTURING ESTABLISHMENTS [21]

If allowance is made for changes in the scope of the enumeration, the number of establishments engaged in manufacturing showed an increase at each census up to 1919 inclusive (see Table 14). But the census of 1921 showed an 8.5 per cent drop in number, the next census very little change, and 1925 a further drop of 4.5 per cent. The censuses of 1927 and 1929 showed percentage gains of 2.4 and

[21] The *1919 Census of Manufactures* included establishments with annual product valued at $500 or more, whereas all subsequent censuses have been limited to those with products valued at $5,000 or more. In this section, establishments with value of product less than $5,000 have been eliminated from the statistics for 1919.

10.0 respectively. The net result of these changes is that between the census of 1919 and 1929 the total number of establishments in all industries combined decreased 3,714. But this is far from an adequate indication of the number that passed out of the industrial picture in this decade. The losses in number in the declining industries are neutralized in large part by increases in the expanding industries. And even within a single industry, old plants may be abandoned and new ones put into operation without changing the total number reported in the census. Full information upon the number of abandoned plants is not available, but helpful clues can be obtained by a closer examination of the changes in the individual manufacturing industries.

Table 22 presents the change from 1919 to 1929 in the number of establishments in each of the 12 industries in which the decline in number exceeded 200. If the industries listed were classified in more detail the decreases would doubtless be shown as even greater than is suggested by the total, 18,408, for one part of an industry may be expanding while another part is declining. For example, in the dairy products group of the food industries, from 1919 to 1929 the number of establishments shows a loss of 624, but in this group the cheese industry alone had a loss of 638, and butter of 121, while condensed and evaporated milk showed a gain of 135.

Even if we utilize a quite minute classification of the industries, the recorded decline often understates the number of establishments in an industry which have gone out of business since the previous census, for in the same period new establishments enter the industry. Thus, there were 103 fewer establishments in 'Boots and shoes other than rubber' in 1927 than in 1925, but 283 concerns went out of business between the census of 1925 and that of 1927. Likewise in

TABLE 22

INDUSTRIES IN WHICH THE NUMBER OF ESTABLISHMENTS DECREASED 200 OR MORE: 1919–1929 [1]

(ranked in order of losses)

INDUSTRY	NUMBER OF ESTABLISHMENTS [2]		DECREASE 1919–29	
	1919	*1929*	NUMBER	PER CENT
Total, 12 industries	77,195	58,787	18,408	23.8
Flour and other grist-mill products	9,209	4,022	5,187	56.3
Lumber and timber products	16,016	12,915	3,101	19.4
Cigars and cigarettes	4,336	1,636	2,700	62.3
Marble, granite, slate and other stone products	3,296	1,881	1,415	42.9
Copper, tin and sheet-iron work	3,522	2,161	1,361	38.6
Bread and other bakery products	21,988	20,785	1,203	5.5
Motor-vehicle bodies and parts	2,123	1,154	969	45.6
Saddlery and harness	1,045	260	785	75.1
Cheese	3,396	2,758	638	18.8
Foundry and machine-shop products	9,323	8,880	443	4.8
Clay products and non-clay refractories	2,113	1,749	364	17.2
Cooperage	828	586	242	29.2

[1] Computed from data in *Census of Manufactures.*

[2] Excluding establishments with value of product less than $5,000.

'Motor vehicles' there was a decline of 33 establishments, but 36 went out of business.

The declines, 1919–29, in the number of establishments were proportionally heavier in some of the smaller industries than in those shown in Table 22. For example, among industries which show declines of between 100 and 200 establishments, the losses exceeded 50 per cent in 'vinous

liquors', 'carriage, wagon, sleigh and sled materials', 'feathers and plumes', and 'pianos'.

Declines in the number of establishments from one census period to another may be due to permanent abandonment of plants, temporary idleness through the census year without permanent abandonment, transfer of individual establishments from one industrial classification to another,[22] decline in total value of product below $5,000, or possibly to variations in the thoroughness with which the census is taken. As 1919 and 1929 were both decennial censuses, and 1929 an active year, it seems plausible that temporary idleness or change in scope does not account for many of the declines evidenced from 1919 to 1929. Some of them may be due in part to changes in classification of individual plants but the shrinkages are so great in many industries that it is difficult to escape the conclusion that in many lines of manufacturing there is a persistent tendency in recent years towards a decrease in the number of establishments.

The question arises, are the observed decreases in the number of establishments only in the decadent industries, or do they indicate tendencies even in the expanding industries. The four small industries with losses of over 50 per cent in the number of establishments, mentioned above, were all industries in which the average number of wage earners declined sharply from 1919 to 1929. Also, of the 12 industries with declines of 200 or more in the number of establishments set forth in Table 22, 7 show declines also in the average number of wage earners. But the remaining

[22] Each establishment as a whole is assigned, on the basis of its product or group of products *of chief value,* to some one industrial classification; hence if a plant produces more than one product a shift from one census to another in the proportions among the several products may change the classification to which the industry is assigned.

5 industries [23] gained in number of wage earners despite the decrease in number of establishments. The net result, of course, is an increase in the average number of wage earners per establishment.

SIZE OF ESTABLISHMENTS

A tendency towards larger plants does not necessarily mean increased mechanization, for a large plant may conceivably have a greater proportion of hand work than a small plant. However, large-scale production ordinarily facilitates the economical use of expensive machinery, and hence an increase in the average size of establishments may be interpreted to indicate at least an opportunity for greater mechanization.

In 1899 the average number of wage earners per establishment was 22.7; in 1909, 24.6, and in 1919, 31.4. These figures cover all establishments with annual product valued at $500 or more. In later censuses the minimum has been set at $5,000. If the establishments with annual product valued at less than $5,000 are excluded from the 1919 census data to make them comparable with 1929, the average number of wage earners per establishment in all manufacturing industries combined is 42.0 in both 1919 and 1929. Evidently the tendency for the size of establishments to increase which was exhibited in the first two decades of the century is not clearly evident in the 1919–29 period, at least not for all industries combined.[24]

[23] Marble, granite, slate and other stone products; copper, tin and sheet-iron work; bread and other bakery products; motor-vehicle bodies and parts; and clay products.

[24] In *Recent Economic Changes* (National Bureau of Economic Research, 1929), the change in size of establishments in individual industries from 1914 to 1925 is analyzed. Eighteen industries at least doubled their average number of wage earners in this period. A few of these, such as aircraft and

There are still many small manufacturing establishments, though the number of establishments employing between 6 and 20 wage earners declined slightly from 54,317 in 1919 to 53,524 in 1929.[25] Slight gains were shown in the number of establishments with over 250 wage earners, which increased from 6,366 in 1919 to 6,558 in 1929. But it is evident that for any marked indications of a tendency towards increasing concentration of production in large units we must turn to an analysis of individual industries rather than the aggregate of manufacturing establishments.

INCREASING CAPACITY OF MACHINE UNITS

One generally observable trend in the character of mechanized equipment is the enlargement of the capacity of the machine unit, either by increasing the physical size of the machine or the speed at which its parts function. As such changes are frequently accompanied by less than proportionate increases in the operating crew and thus change the

motor-vehicle bodies and parts, are industries which expanded greatly. Others increased their average number of wage earners chiefly by reducing the number of establishments. On the other hand, some industries declined in average size. The 15 industries reporting the greatest decline in the number of wage earners per establishment, 1914–25, were mostly industries which had suffered from loss of markets with the result that they reported decreases also in the total number of wage earners.

Likewise, in *Economic Tendencies in the United States,* pp. 305–6, Dr. F. C. Mills computes the average annual rate of change, 1923–29, in average number of wage earners per establishment in each of 60 industries. Increases ranging from 0.1 to 9.8 per cent occurred in 35 industries. In 25, there was no change, or there were declines of from 0.1 to 12.7 per cent. The average for the 60 industries was an annual increase of 0.4 per cent.

[25] Establishments with 5 or fewer wage earners declined from 166,315 in 1919 to 103,913 in 1929, but a large part of this decline arises from the fact that in 1919, although not in 1929, establishments with product of $500 but less than $5,000 were included and most of these would be in the group with 5 or fewer employees.

ratio of equipment to workers, they may appropriately be described as increases in the mechanization of industry.

In Table 23 we have assembled several series of statistics which indicate the changing size of specified types of equipment from 1909 to 1929. The accompanying text in some

TABLE 23

ILLUSTRATIONS OF TENDENCIES IN CAPACITY OF INDIVIDUAL EQUIPMENT UNITS

TYPE OF EQUIPMENT	*1909*	*1914*	*1919*	*1923*	*1925*	*1927*	*1929*
Freight cars, average capacity in tons [1]	35.3	39.1	41.9	43.8	44.8	45.5	46.3
Steam locomotives, average tractive power in thousands of pounds [1]	26.6	31.0	35.8	39.2	40.7	42.8	44.8
Average annual capacity of cement kilns [2] (1000 bbls.)	93	137	186	204	223	252	283
Average daily output, in tons, of active blast furnaces [3]	263	332	343	397	459	507	570
Average horsepower of power units in factories [4]							
Steam engines and turbines	92.7	113.7	139.1	185.4	205.9	230.6	224.8
Internal-combustion engines	21.9	26.3	40.8	77.9	82.6	92.4	109.3
Water wheels and turbines	8.6	10.1	12.6	19.4	21.5	21.1	23.9
Electric motors driven by purchased power	8.8	8.6	9.5	9.4	9.2	8.9	8.4
Electric motors driven by power generated in the same establishment	16.2	15.4	14.3	14.3	13.3	14.2	14.5

[1] Compiled from Interstate Commerce Commission reports on *Statistics of Railways in the United States.*

[2] Computed from statistics of annual capacity as given in United States Geological Survey, *Mineral Resources of the United States.*

[3] Computed from data published in *Iron Trade Review.*

[4] Computed from statistics of horsepower and number of units in *Census of Manufactures for 1919,* p. 122, and *1927,* p. 1270.

instances cites earlier data from the same source. Rarely does the unit size decrease in the later periods; rather as a rule it increases as the years go by.

In railway transportation the trend towards larger equipment units is striking. The average capacity of freight cars has increased from 29.4 tons in 1903 to 35.3 in 1909, and 46.3 in 1929. Likewise, the average tractive power of locomotives has increased from about 22,000 pounds in 1903 to nearly 45,000 pounds in 1929.

In the blast furnace industry the tendency towards larger stacks is indicated by the rapid increase in daily capacity per stack from 230 in 1907 to 570 in 1929. The increase in man-hour productivity in merchant blast furnace operation has been ascribed in large part to the increase in average daily stack output, and this in turn chiefly to the increasing size of the stacks (B.L.S., Bul. 474, Ref. 37, pp. 32–41).

Rotary cement kilns

One feature of the rapid development of the cement industry in the present century has been an increase in the size of the rotary kilns.[26] In 1910, of the 845 kilns for which lengths are specified in the directory of the cement industry the mean length was 92 feet, the modal length 60 feet. In 1922, only 12 years later, the average length of 644 kilns for which dimensions are given was 118 feet, with the modal length 125 feet (127 kilns). In 1906 only 7 per cent of the kilns in active plants were 125 feet or more in length; by 1910 the percentage had risen to 21; and by 1917 to 43, where it remained for several years.

The same tendency is evidenced by a study of the length

[26] The statistics in this paragraph have been compiled, unless otherwise indicated, from the directories of the cement industry, published annually in recent years by *Cement, Mill and Quarry*.

of kilns in new plants. Of the 7 kilns in plants reported as producing for the first time in 1913 the longest was 170 feet; of 14 new kilns in 1916, 3 were 200 feet or longer, while of 28 new kilns added in the active year 1927 half were over 200 feet long, one of these being 300 and another 343.

Length is closely associated with capacity. In 1922 the average stated capacity was 196 barrels for 60-foot kilns, 623 for 125-foot, 1,125 for 175-foot, 938 for 200-foot, and 1,400 for 240-foot kilns. Hence it seems reasonable to assign the increasing length of kilns as one cause of the increase in the average annual capacity of cement kilns (given in Table 23) from 93,000 barrels in 1909 to 283,000 in 1929.

Power units in factories

As shown in Table 23 the average size of steam engines and turbines, internal-combustion engines, and water wheels and turbines has increased steadily from 1909 to 1929. On the other hand, there has been relatively little change in the horsepower of electric motors, whether driven by purchased power or by power generated in the plant using the motors. Apparently the increasing use of individual electric motors for small machine units has more than offset the tendency of the increasing size of many types of power-driven equipment to require larger electric motors.

Numerous other instances of the increasing physical size of machine units have come to our attention in studying the nature of the labor-saving changes in the plants included in our survey or as described in the technical literature. In highway construction the introduction of caterpillar tread has furthered an increase in the size of cement mixers (Ch. IV). In the glass bottle industry the capacity of the Owens automatic bottle machine has increased with the later

models. In the cement industry not only has the length of the kiln tended to increase, as noted above, but also larger and more powerful crushers have been developed (Ch. III). In the milling process in the rubber industries the introduction of larger rolls without an equivalent increase in the force of machine tenders has been a major factor because much of the work of the tender is merely waiting for the machine to do its part (Ch. III). In paper making the paper machine has steadily increased in both width and running speed, and likewise in the pulp-making department the digesters and grinders have substantially greater capacity than formerly (Ch. III, Table 4). In the brick industry the brick machines that had been recently installed had larger capacities than the displaced machines.

The increase in the physical size of factory machinery has been furthered by the development of mechanical handling devices capable of lifting and moving materials or product in larger units than could be readily handled by manual methods.

In farming the sales of large harvester and thresher combines, for example, rose suddenly in 1923, as compared with the small machines. In 1921 a total of 4,610 combines with a width of cut 10 feet or less were sold, and only 417 with cut over 10 feet. In 1923 the situation was reversed, 219 being 10 feet or less, and 3,793 over 10 feet. Similar data are not given in the later statistics of farm machinery sales.

INCREASING CAPACITY THROUGH GREATER SPEEDS

The capacity of a machine may be enlarged by making the machine run faster rather than increasing its physical size. For example, the capacity of the auger type of brick-molding machine has been enlarged without resorting to "design of larger dimensions of barrel". These machines

have almost exclusively rotary movements, and more capacity has been obtained by greater speed or number of revolutions. "An auger shaft speed of 25 to 30 revolutions per minute in 1914 is now often from 40 to 50 revolutions per minute, without undue breakage of parts." [27]

Such an acceleration of running speed has been made possible by the more durable machine parts and better lubricating systems. Interchangeability of parts in machines produced in large quantities has also contributed to the acceleration in actual running speed by reducing stoppages for repairs. A quotation from a letter from a veteran manufacturer of brick machines illustrates this development:

> "The signer of this has been since May 1871 (57 years) connected in various capacities with foundry and machinery concerns that served brick manufacturers. During the first 20 years the service rendered was wholly making parts for and keeping in repair machinery of various makes which, without exception, produced a minimum of both quality and quantity at maximum cost of both cash and lost time for upkeep. The brick manufacturer who tried to carry a stock of parts from the manufacturer of his machines frequently found their foresight of no avail because the parts were not interchangeable, so the roads between brickyard and our shop were kept hot while the gang loafed."

We noted in Chapter III that an outstanding development in wood-working machinery in recent decades has been accelerated lineal speeds of such machines as flooring machines and molders. In the garment-making industry various establishments reported labor reductions through the purchase of more rapid sewing machines. In paper pulp making, the manufacturer has reduced labor costs by running machines faster without increasing the number of tenders. One paper-machine manufacturer writes: "a machine running at three or four hundred feet per minute will require approximately the same amount of help in the machine

[27] Letter to writer from president of a leading brick machine company, April 16, 1928.

rooms as a machine running eight hundred or a thousand feet per minute or over." One manufacturer of corrugated fibre-board products reported to us that by increasing the speed of his machines he had been able to "triple production since 1920 with approximately the same number of employees".

The superintendent of a beet sugar factory states: "We have done more in increasing the speed of the existing machinery by little odds and ends, each one more or less insignificant in itself, by all working together to increase the speed and by training the crews to quicker and snappier work."

A knitting mill reported that it was introducing new knitting machines which would run 20 per cent faster, make 24 stockings at once instead of 18, and, as were the slower machines, be tended by one man.

English cotton mills are said to make up in part for fewer looms per weaver by running looms at a higher speed. In the warping process in American mills the new-type high speed warper is said to run something like eight times as fast as the old-style warper, though the saving in labor is not so great as this ratio might imply (Ch. III).

ELECTRIFICATION OF FACTORY POWER EQUIPMENT

Because of its cleanliness and flexibility, electrification facilitates the more general application of power in industry; hence the pronounced trend towards the electrification of manufacturing plants, clearly brought out by Table 24, is a significant aspect of increasing mechanization. From 4 per cent in 1899 the percentage of power equipment which is electrified has increased to about 30 in 1914, and to about 70 to 75 in 1929.

A precise determination of the degree of electrification

TABLE 24

INCREASING USE OF ELECTRIC POWER IN MANUFACTURING[1]

CENSUS YEAR	A	B	C	D	E	F	G
	RATED HORSEPOWER (THOUSANDS)						
	Total primary power (B+C)	*Other than electric*[2]	*Electric motors driven by purchased power*	*Electric motors driven by current generated in reporting plant*	RATIO OF ELECTRIC MOTORS DRIVEN BY PURCHASED POWER TO TOTAL PRIMARY POWER $(C \div A)$	ELECTRIFICATION RATIOS Method I[3] $\left(\frac{C+.72D}{A}\right)$	Method II[4] $\left(\frac{C+D}{C+1.39B}\right)$
1899	10,098	9,915	183	310	.02	.04	.04
1904	13,488	13,046	442	1,151	.03	.10	.09
1909	18,675	16,926	1,749	3,068	.09	.21	.19
1914	22,437	18,540	3,897	4,939	.17	.33	.30
1919	29,324	20,041	9,283	6,969	.32	.49	.44
1923	33,092	19,728	13,364	8,821	.40	.60	.54
1925	35,767	19,902	15,865	10,255	.44	.65	.60
1927	38,826	19,693	19,132	11,220	.49	.70	.65
1929	42,931	20,155	22,776	12,376	.53	.74	.69

[1] Compiled from *Census of Manufactures: 1919,* VIII, 122; *1927,* p. 1270, and *1929,* p. 112. Unlike the data in Table 15 these data are not adjusted for changes in the scope of the census of manufactures.

[2] Includes steam engines, steam turbines, internal-combustion engines, water wheels and water turbines, in the reporting plant; also, for 1899–1914, rented power other than electric. Some of this non-electric power is used to generate current to drive electric motors; hence, to avoid duplication, the horsepower of electric motors driven by current generated in the reporting plant (shown in column D) is not included directly in the total for primary power in column A.

[3] In Method I, which is used by the Bureau of the Census to estimate the "Proportion of 'Electrification' of Factory Power Equipment", the horsepower of electrified equipment is taken as the sum of electric motors driven by purchased current plus the estimated capacity of prime movers used to actuate motors operated by prime movers owned by the reporting factory. It is assumed "that the ratio of the capacity of these prime movers to that of the motors operated by them is 72 per cent". The denominator of the ratio is total primary power; *Commerce Yearbook* (1929), I, 292.

[4] In Method II, the numerator of the ratio is the total of electric motors in the factory, both those operated by purchased power and those operated

by power generated in the factory; and the denominator is the estimate total of electric motors if the plants were all completely electrified. In mal ing this estimate we have followed the Bureau of Census in assuming tha 72 horsepower of prime movers will be used to drive 100 horsepower o electric motors.

is made difficult by the fact, noted above, that the horse power of electric motors driven by purchased power is no logically comparable with the horsepower of prime mover used to drive machinery directly or to generate power fo electric motors in the same establishment. In computing th degree of electrification we have assumed that 72 horsepowe of prime movers will be used to drive 100 horsepower o electric motors, and have computed the degree of electrif cation by two slightly different methods, as explained in th footnotes to Table 24. The estimate in column F follows th method used in the *Commerce Yearbook* and yields an ele trification ratio for 1927 of 70 per cent. The slightly mor conservative method in column G yields an estimate of 6 per cent. Using a still different method of estimate, Mr. I P. Alford reaches a figure of 78 per cent for 1927.[28] By al three methods the degree of electrification is shown to hav at least doubled from 1914 to 1927.

Since 1914 there has been a large increase in the numbe of electric motors operated by power generated in the sam establishment, but the increase in the use of purchase power has been even more marked—from less than 4 millio horsepower in 1914 to over 20 million in 1929.

The increase in the use of electric power has been com mon in many industries. A few specific illustrations may b cited. In the rolling mill branch of the steel industry th greatest change in the last ten or fifteen years has bee associated with the electrification of main roll drives and a incidental controls, which is the method of automatic pr

[28] *Recent Economic Changes*, p. 126.

uction.[29] Electrification has been especially rapid since 923 in several of the rolling mill processes. Electrification urthers the use of individual drives. In machine tools, to llustrate, there is a marked tendency towards the substitu- ion of group or individual motor drives for pulley drives. For example, the *American Machinist,* in its summary for ew machine-tool equipment for the second half of 1927, ointed out that "self-contained motor drives are now the ule rather than the exception, and pulley drives are usually ptional".[30] The same issue of the *American Machinist* also alls attention to the "large number of portable electric drills" put upon the market.

Some of the reasons for the growing popularity of electric ower in factories are suggested by the following quotation rom the *1910 Census of Manufactures* (VIII, 331).

"Electric power is largely applied by means of relatively small motors distributed throughout the manufacturing establishment, some of which are n general use while others are required only at infrequent intervals. As he electric power can be used or cut off at will, it proves both convenient nd economical, especially for the operation of machinery which is in use nly a part of the time; and the cleanliness and quietness of the electric notor as compared with other sources of power also give it manifest dvantages in certain industries, such as the clothing industries. . . . The lectric motor run by purchased current furnishes power for manufacturing vith a minimum of trouble or attention on the part of the operator. . . ."

CONOMY OF MEN AND EQUIPMENT

Our major concern in this survey is with the changes in he type and quantity of machinery used. Lest this preoccu- ation with the trends in mechanization make it appear that ve are overlooking non-mechanical changes, let us reiterate hat there are also in progress in American industry various

[29] See Ch. III and Appendix A.
[30] January 19, 1928, p. 77.

non-mechanical changes in organization and methods o operation, not readily susceptible of measurement with r spect to their extent and rapidity of introduction but neve theless of significance in the past history and for the futu development of industry. We have in mind all those tec niques included under the none too clearly defined ter scientific management, with its time and motion studies, al improved methods of wage payment, and increasing su division of labor, such as sometimes accompanies t 'stretch-out' system in textile mills—in short, all efficienc measures which represent a more effective use of the avai able machinery and man power rather than changes in t equipment itself.[31]

[31] See Ch. II, section on Non-mechanical Changes; also Ch. III, pa ticularly sections dealing with Cotton Yarn and Cloth, Newspaper Printin Leather, and Beet Sugar.