AN INCENTIVE PLAN FOR A BLAST FURNACE

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PREFACE

Frequently wage incentives have failed because of the lack of plausible presentation of the plan. An industrial engineer can usually design a better wage incentive plan if, in considering the basis and details, he bears in mind that the plan must be sold to the operating supervision and workmen. The general outline of this thesis was conceived before the plan was fully developed. For this reason, the theme is divided between sales and development.

It is unfortunate that a flood of the Ohio River in 1937 destroyed all of the original time study data and compilation sheets. Thus, there is nothing to substantiate the data contained in the few copies of the Standard Practice Bulletins saved from the flood. Most of the charts containing unit and capacity values have been omitted at the suggestion, though not the request, of the company. It is the plan of procedure and the principles involved that are of value to others rather than the resulting values.

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CHAPTER I

INTRODUCTION

> The blast furnace, even in its highest development, is by no means the even-going, easily regulated monster the casual observer may take it to be. Although furnace operations are under better control now than ever before, the furnace man knows his furnace is capable of acting in the most unexpected and astonishing ways. Therefore, a full discussion of this subject would lead to possibilities and probabilities almost without end. However, the subject lends itself to one positive statement. It is this: There are few situations in life where promptness and decision, forethought and judgment, skill and experience, are more needed than about a blast furnace in trouble.[1]

Furnace men know, too, that a furnace in trouble is not producing iron to its capacity. It is further known that much of this trouble can be eliminated by the proper attention to duty by every member of the organization. In general, it might be said that if management supplies materials of specified quality, the superintendent calculates the burden correctly, and the workmen perform their tasks not only correctly but at the proper time, a furnace should produce its maximum.

An incentive plan should be designed so that workmen will receive additional pay in proportion not only to the individual effort expended but also in proportion to the degree of furnace capacity utilization.

The purpose of this thesis is to describe the development of a wage incentive plan which fulfilled management's desire for effective utilization of both labor and equipment. In addition to a wage incentive to labor, this plan provided standard data for such management techniques as cost finding, production scheduling, raw material and supervisory control.

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[1] J. M. Camp and C. B. Francis, The Making, Shaping and Treating of Steel, p. 191

CHAPTER II

GENERAL DESCRIPTION OF THE FURNACE AND PROCESS

General Description of a Blast Furnace

In general, the central unit of a blast furnace is the furnace itself with its skip hoist for handling charges, and bins for storage of ore, limestone, coke and scrap iron. In addition, and only slightly less important, are the hot blast stoves, blowing engines, and boiler plant.

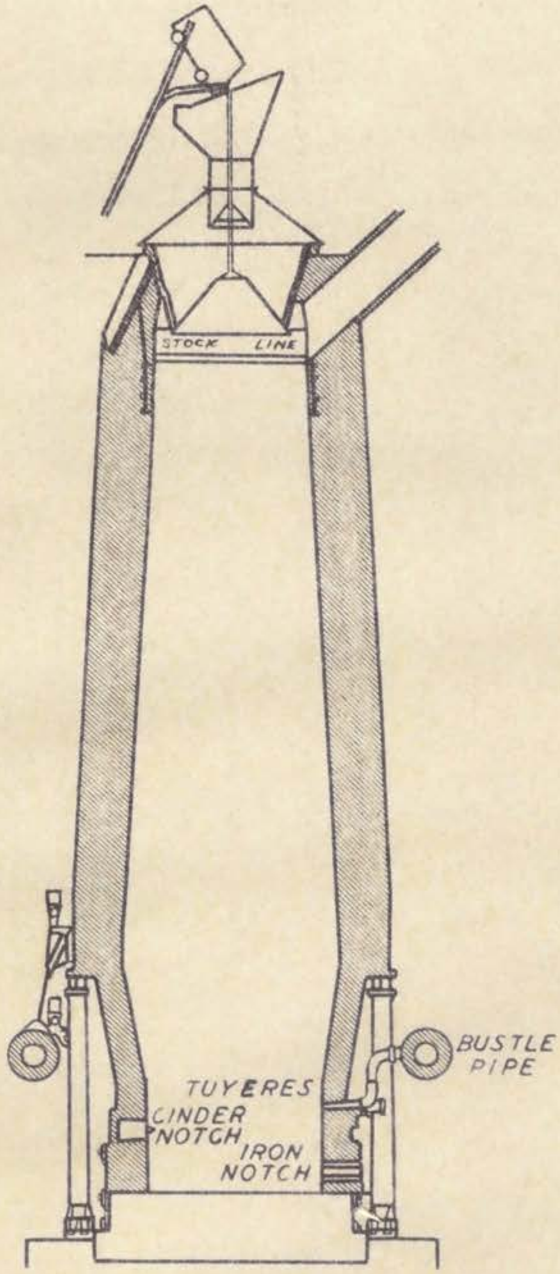
The furnace proper consists of an enclosed space or shaft to hold and reduce the materials, and a hearth to collect the molten products.

The shaft is in the form of two truncated cones placed base to base (see diagram on next page), surmounting the hearth. By such arrangement the materials are given room to expand with the temperature as they descend the shaft. As the materials approach the zone of fusion, the converging walls offer support to the lessening volume. The hearth serves to hold the liquid slag and iron until enough has accumulated to be drawn off.

The dimensions of a furnace vary widely, but are generally proportional in well-designed units.

The bustle pipe, a large doughnut-shaped pipe surrounding the furnace just above the tuyere level, distributes the hot blast. The tuyeres are especially designed orifices to conduct the blast into the furnace.

The stoves consist of checker chambers of fire brick encased in steel jackets. Part of the blast furnace gases are burned in a specially designed fire box in order that the products of combustion may pass through the checker chamber to heat the brick.



VERTICAL SECTION OF A MODERN BLAST FURNACE

OM: THE MAKING, SHAPING & TREATING OF STEEL, J.M. CAMP & C.B. FRANCIS, 4TH ED.

When the checker chamber has been heated sufficiently, the gas is turned off and atmospheric air is forced through it to be pre-heated before entering the furnace. Usually, three or more such stoves are available for each furnace. The design of the stoves is such that one can be heated in about the time it takes the blast to cool off another. The third is kept in reserve.

The blowing engines, usually driven by steam or internal combustion engines, are used to force the blast through the stoves into the furnace. These engines ordinarily deliver from 20,000 to 60,000 cubic feet of air per minute at approximately 30 pounds pressure.

The capacity of the boiler plant will vary with the number and type of auxiliary equipment. Usually the blowing engines are driven by steam. The boiler plant is generally designed to consume the blast furnace gas in excess of the amount consumed by the stoves.

General Description of the Smelting Process

The process of producing pig iron from iron ore consists essentially of charging a mixture of coke, iron ore, scrap iron and limestone in the top of the furnace, while blowing a current of heated air in at the bottom. The air burns the coke, producing the heat for chemical reactions and for smelting the ore. The gases formed by this combustion remove the oxygen from the ore, changing it to metallic iron. The flux of lime removes earthy and other foreign materials. The gases pass out the top of the furnace while the iron and slag drop in liquid form to the hearth and are tapped at the bottom. The escaping gases are combustible and are conducted through pipes to the boiler room and stoves to develop steam power and to heat the air for the blast. In some cases, as noted before, these gases are used to operate internal combustion engines.

CHAPTER III

FACTORS CONTROLLING BLAST FURNACE PRODUCTION

The factors which control blast furnace production may be classified, as to responsibility, under four main headings. They are (1) Management, (2) Nature, (3) Supervision, and (4) Workmen.

Management

When the stack and its auxiliary equipment are procured, the main factors determining possible production are established. Next, the demand for the production of a specific grade of iron further establishes limitations on production. Knowing the grade of iron required, management can then purchase raw materials - ore, scrap iron, other iron-bearing materials, limestone and coke. These factors, being entirely within the control of higher management, must be accounted for in the standards.

Nature

The blast furnace, being what it is, demands that most of the equipment and labor be exposed to the elements. Extremes in heat and cold definitely affect both equipment and human efficiency. The blast furnace in question burns approximately 42,000,000 cubic feet of atmospheric air in twenty-four hours. Tests show that a variation of as much as ten grains of water must be disassociated on some days than on others. The disassociation of 28 tons of water consumes 18.67 tons of coke that could be used to produce more than 20 tons of pig iron. It also introduces a condition within the furnace that requires considerable experience, skill and diligence to detect and make the adjustments necessary to prevent an "off-grade" cast. Operators on incentive are much more likely to be on the alert for such a condition, and very much more likely to make the necessary adjustments to compensate for the change in moisture in the blast.

Supervision

Blast furnace supervision has two main responsibilities toward good production:

1. Calculation of the burden
2. Coordination of the workmen

Burdening a furnace involves the calculation of the proper sequence and amounts of the various grades of ore, scrap iron, limestone and coke necessary to produce the grade of pig iron required. The calculation of the burden not only requires a complete knowledge of the metallurgy of a blast furnace but also a thorough knowledge of the individual eccentricities of the furnace involved. One person, usually the superintendent, is charged with the responsibility for the proper burden. Turn foremen and workmen share the responsibility for charging the burden correctly.

The blast furnace is so constituted that the workmen cannot be observed by the foremen at all times. These men work in isolated groups, usually under a group leader. Under such conditions, the best foreman cannot be expected to secure complete cooperation without incentives.

Workmen

If labor were always absolutely loyal, aggressive and thoroughly trained, many of the industrial ills could be avoided. Past practice has indicated that normal labor must be supervised directly, or placed on incentives, to secure reasonable returns for wages paid. No place is this more true than in a blast furnace. Small variations in the desired sequence or amounts of each charge, even though the total be correct, can and do affect the quantity and quality of production. Regularity and precision are of the greatest importance. For example, it is essential to capacity operation that a steady flow of the proper charges be delivered into the top of the furnace. This precludes the possibility of a "dommy" (rest period), so common among blast furnace workmen. The inability of supervision to be every place at one time has permitted the growth of the dommy to the proportions of a "constitutional right" among furnace men. They work diligently and fill the furnace above the normal "stock line" (proper level for stock within the furnace), then rest until the level is considerably below normal. This results in a decided fluctuation in the gas pressure within the furnace and the distribution of the larger material (usually coke and limestone) against the side walls. As a result, the reducing gases, following the lines of least resistance, pass through the coke and limestone instead of the ore, and are largely wasted. As this coarser material approaches the zone of combustion, the burning takes place against the side walls, wasting much of the heat and causing excessive wear on the brick lining. A more detailed description of the ills occasioned by the dommy would be out of place here; suffice it to say that much of the variation in furnace production, both in quantity and quality, is rooted in this practice. Quantity and quality incentives can be a real aid to supervision in improving this situation.

The Industrial Engineering Department believed that an incentive plan emphasizing good capacity attainment, modified by labor effectiveness, would do much toward increasing the quality and quantity of production.

CHAPTER IV

HISTORY OF PLAN

Early in 1930, Mr. George P. Hanson, then general superintendent of the Ashland, Kentucky, Division of the American Rolling Mill Company, requested an incentive application to the two blast furnaces operated by the Division. Studies were made, indicating a possible reduction of 27% in the labor costs through systematized methods of work and a combination of jobs. Knowing that all practical plans for incentives lead inevitably to a capacity application, management was skeptical of the practicability of capacity standards applied to a furnace. Mr. Hanson stated that, "No one had been able to develop blast furnace production standards of sufficient accuracy for use in the application of incentives." Mr. C. J. Rice, the blast furnace superintendent, inferred that he and Nature, not the workmen, controlled furnace production. Our studies of the furnace and furnace men convinced the writer that labor influenced production as much as any other factor.

Months followed, during which past records of production, atmospheric temperatures and relative humidity, blast temperatures, chemical analyses of pig iron and coke consumption, and furnace conditions in general were tabulated and analyzed. There seemed to be a basis for blast furnace production standards, and as a result, these data were summarized, presented, and applied.

In 1941 Mr. Hanson, now general manager of the Benwood Plant of Wheeling Steel Corporation, requested his chief industrial engineer, Mr. S. J. Turner, to secure from the writer the methods and procedures necessary to the development of similar standards for all of Wheeling Steel Company's blast furnaces. The intervening years had proven the standards, which had remained the same except for minor adjustments due to changes in the grade of iron produced and the grade of coke available. In 1939, the hot blast at the Ashland plant was dehydrated to 1.6 grains of moisture per cubic foot, necessitating another slight change in standards. Incidentally, it was these standards which first focused management's attention on the losses occasioned by the moisture in the air, and eventually resulted in the conditioning of the hot blast.

CHAPTER V

DEVELOPMENT OF CAPACITY

Definition of Capacity

One hundred percent of capacity is that production performance which can be obtained under favorable operating conditions with diligent application to controllable factors. It is anticipated that true capacity performance will never vary in excess of plus or minus 3% from the calculated capacity. Calculated standard production for normal or nearly normal operating conditions should seldom be at variance with maximum potential production more than plus or minus 1%. Percentage of capacity may be obtained by dividing actual production by the standard production.

General Bases of Capacity Standards

In a blast furnace there are five main groups of factors which can influence the quantity and quality of production:

1. Equipment available
2. Materials supplied
3. Grade of iron made
4. Atmospheric conditions
5. Labor

Of these, Items 1, 2 and 3 (equipment, materials and grade of iron) are definitely controlled by management and will be accounted for in the standards. Of course, the equipment may be allowed to depreciate, but it will be assumed that an incentive plan will be so arranged that maintenance labor will keep the equipment in top operating condition.

Atmospheric conditions are beyond human control, except when the hot blast air is conditioned, and must be accounted for in any set of equitable standards.

We shall assume that the monetary incentive plan to be applied will be of such character that furnace workmen will find it to their advantage to perform their tasks correctly and with dispatch. The workman's premium earnings will be modified by the percentage of capacity attained. It is anticipated, therefore, that each workman will cooperate with others to the end that a maximum capacity can be attained and maintained.

Furnace capacities will be calculated weekly in order to secure a reliable production tonnage. It is possible, even without forethought, not to drain the hearth of all the iron in one cast, and to take advantage of this additional tonnage the next. "Off-grade" casts will be included in capacity calculations only to the extent of their value to the company. A condition which causes "off-grade" casts cannot be corrected immediately. Further, these corrective measures often entail loss of production. For these further reasons, capacity should be calculated weekly, or for the normal pay period.

Specific Equipment

Briefly, the furnace and equipment of the specific unit in question may be described as follows:

1. Furnace

   a. Height, 82 feet and 1 inch
   b. Diameter, bosh, 18 feet and 2 inches
   c. Diameter, hearth, 14 feet and 6 inches
   d. Diameter, stock line, 13 feet
   e. Diameter, bell, 9 feet

2. Skip

   McKee top skip hoist

3. Blowing Engines

   a. 2 Weimer, 5 foot stroke, 7 inch diameter high pressure
   b. 2 Allis Chalmers, 5 foot stroke, 7 inch diameter low pressure

4. Stoves

3 - 80 feet high, diameter 20 feet, 60% of checker chamber consisting of fire brick

Production Capacity of Available Equipment

The first step in an analysis of a furnace is to determine the ability of that unit to burn coke. This is determined by the size of the stack, the amount of available blast, and the physical and chemical characteristics of the coke.

1. Working Volume of the Furnace

The working volume of a furnace is that portion in which actual combustion of coke or reduction of ore to iron can proceed. Theoretically, this should constitute the entire volume of the stack from the center line of the tuyeres to a point just far enough below the bell to permit its opening and closing. Many of the existing and definitely usable furnaces today were built before standard dimensions were proved and accepted. Errors in the angle of the side wall can usually be corrected when the furnace is rebuilt. Errors in height are there to stay. In the furnace in question, the error in height was about four feet. This was determined by suspending thermocouples at various depths to determine the temperature and by taking samples of the furnace gases at varying distances from the top. With this information, it is relatively easy to determine just where reduction of the ore starts. Assuming that no reduction took place above this plane (four feet below the bell when closed), the "working" or remaining volume of the furnace was calculated at 12,336 cubic feet.

The Southern Ohio Pig Iron and Coal Association (S.O.P.I.C.A.) has determined that a carefully designed blast furnace should burn

60 pounds of normal coke (90% fixed carbon) in 24 hours for each cubic foot of working volume. On this basis, this furnace can consume 740,160 (12,336 cubic feet x 60#) pounds of coke in 24 hours. It should be noted, however, that this rate of combustion specified by S.O.P.I.C.A. is only a general guide and does not apply exactly to every furnace.

2. Volume and Temperature of the Blast

a. Volume

Theoretically, 53 cubic feet of air at 60° F. and 14.7 pounds pressure are required to burn one pound of coke within the furnace. However, under actual conditions, somewhat more air must be delivered by the blowing engines. Small leaks are sure to develop in the pipe lines even with diligent attention by the maintenance crews. Small amounts of air are lost in changing the stoves every hour.

Good practice indicates that under actual operating conditions it will require approximately 58 cubic feet of air at 60° F. and 14.7 pounds pressure, to burn one pound of the available coke.

The blowing engines take in 380 cubic feet of air each complete revolution and rotate at 39 R.P.M. The blast is turned off an average of 15 minutes each 24 hours to permit plugging the cast and slag holes after each cast. Thus, the blast is on the furnace 1425 minutes a day (24 hours x 60 minutes minus 15 minutes). This makes 42,237,000 cubic feet of atmospheric air available for blast (380 cubic feet x 39 R.P.M. x 2 engines x 1425 minutes). If 58 cubic feet are required for each pound of coke, therefore it can burn 728,241 pounds of coke each 24 hours.

b. Temperature

The temperature of the blast has little effect on the amount of coke that can be burned. A hot blast does produce a greater heat and, therefore, has a direct bearing on the production of a given quality of pig iron. Most furnaces already have the hot blast stoves installed and in use so that, except for a complete re-design, little can be done. However, the "stove tender", by diligent application to his task, insures higher and more uniform heat. A dirty stove is known to be less efficient. One function of a "stove tender" is to clean out the stove at regular intervals or whenever it is required. The hot blast should be maintained at a temperature ranging from 1000° to 1200° Fahrenheit. Tests and observation at the tuyeres will determine at what intervals stoves must be changed to insure uniform heat.

Another factor controlling uniform and sufficient blast temperature is contained in the heating process of the stoves. Again, the knowledge, experience and diligence of the stove tender is a definitely controlling factor.

Inasmuch as the temperature of the blast affects only the temperature of combustion, it will be assumed that the proper blast heat is maintained at all times. This places the responsibility for quality production, insofar as blast temperature is concerned, on operating labor.

By arranging the premium payments so that capacity performance is the predominant influence, sufficient emphasis can be placed on the maintenance of good blast temperatures to insure maximum production of uniform quality iron.

3. Physical and Chemical Characteristics of Coke

Blast furnace coke is produced in large quantities for that purpose alone. Considerable research has been done on coals and coking processes to insure a hard porous coke, high in fixed carbon and relatively free of sulphur and ash. Coke must be hard enough to withstand considerable pressure without crushing. Each individual furnace usually has a local source of coke supply. It is management's responsibility to secure as good coke as possible. A uniform quality of coke can be anticipated because of the present-day control devices on coking ovens. Occasionally it is necessary to change the coking coals, and for this reason the fixed carbon, ash and sulphur content of the coke may change. It is, therefore, necessary to establish definitely the carbon content of the coke available at regular intervals, and if necessary, adjust capacity figures accordingly. The amount of fixed carbon available, rather than the amount of coke, will determine the reduction of ore to iron. (Coke with 90% fixed carbon was available at this furnace.)

4. Other Factors to be Considered

The production of pig iron also depends on the silicon and manganese content. Much higher temperature is required to transfer these metaloids from the ore where they exist into the pig iron. It is not intended that this should be a discussion of the metallurgy of a furnace. Most blast furnaces have established a grade of iron which is produced in quantities and can be adopted as the standard grade. If other grades of iron are produced, standards for this type may also be developed. Steel mills usually produce a grade of iron most suitable to the needs of steel they produce in the open hearth. The analysis of this pig iron will, of course, vary with ultimate physical requirements of the steel. Usually small variations in pig iron analysis can be compensated for in the open hearth. For purposes of this discussion we shall limit development of standards to two grades:

Basic iron	0.6% to 1.0% silicon Trace to 0.8 manganese 3.4% to 3.8% total carbon Up to 0.07% sulphur
Foundry iron	1.8% to 2.2% silicon Up to 2.2% manganese 3.4% to 3.8% total carbon Up to 0.05% sulphur

Sulphur is kept as low as possible by elimination of sulphur from the charge, chiefly by the purchase of non-sulphur coke. The higher temperatures required to produce high silicon steel permits the transfer of less sulphur to the iron.

Study of Past Performance

With the above data in mind, ten years' production records were classified and analyzed to determine actual coke consumption on a daily basis as well as per ton of a given grade of iron. Periods of production were divided into two main classifications, basic iron and foundry iron. Each of these classifications was further divided into other classifications:

1. Production entirely from ore
2. Production from ore and scrap iron

Item 2 above was then segregated into groups of 1% variation in the amount of scrap charged compared to the total tonnage produced.

Good cupola practice indicates that from 7 to 10 pounds of iron can be melted with one pound of coke.[2]

The company operated a cupola in a nearby foundry. Coke consumption on this unit, melting pig iron, averaged 200 pounds of coke per ton of pig melted. Inasmuch as this approached scrap iron in nature, 200 pounds of coke was adopted as standard in the blast furnace. The coke being used

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[2] Robert Forsythe, Blast Furnace and the Manufacture of Pig Iron.

averaged 90% fixed carbon or 180 pounds of fixed carbon per ton of scrap.

Winter operation on 100% ore burden (winter was taken as a basis because of the smaller quantity of water in the air) indicated that during weekly periods of the best average production, 1800 pounds of coke were consumed per each ton of basic pig iron produced from ore. However, all available texts indicated that 2000 pounds of coke was more nearly the country's average. Inasmuch as our average consumption was considerably less, the 2000 pounds could not be established as a standard. The complexity of the metallurgy in a blast furnace precluded the possibility of a theoretical coke consumption that would approach a practical standard. In a conference between the general superintendent, blast furnace superintendent, plant metallurgist and the writer, it was agreed that 1800 pounds of coke of 90% fixed carbon would be used as a standard for basic pig iron. Foundry iron contains more silicon and manganese than basic iron. These elements are obtained by creating higher temperatures which require more coke per ton. By similar analysis and conference, a standard of 1955 pounds of 90% fixed carbon coke was established for foundry iron. Chemical analysis of these two grades of iron can be found on Page 16.

Converting the required coke per ton cited above to carbon per ton, we find:

1. 200 pounds per ton x 90% = 180 pounds of carbon required to melt one long ton of scrap iron
2. 1800 pounds per ton x 90% = 1620 pounds of carbon required to smelt one long ton of basic pig iron
3. 1955 pounds of coke x 90% = 1760 pounds of carbon required to smelt one long ton of foundry pig iron

The calculation of the standard carbon per long ton of actual production can be accomplished by the following formula:

1. 180 pounds of carbon x % of product made from scrap iron + 1620 pounds of carbon x % of product made from ore = standard pounds of carbon per ton of basic pig iron

2. 180 pounds of carbon x % of product made from scrap iron + 1760 pounds of carbon x % of product made from ore = standard pounds of carbon per ton of foundry iron

The percentage of pig iron made from scrap is calculated by dividing the scrap charged into the furnace by the total production. Inasmuch as the losses due to oxidation, etc. are very small and scrap consumption seldom exceeds 25%, the potential error involved in this method is negligible.

Naturally, then, 100 - % of production from scrap approximates the production from iron ores.

The iron content is known for each iron-bearing material of the theoretical burden. Thus, before charging, the percentage of iron to be produced from scrap is available. This necessitates the use of standard acceptable yield figures for each iron-bearing material charged into the furnace. This calculation is somewhat involved and did not improve the accuracy of the capacity standards appreciably. The simpler calculation was, therefore, accepted as standard practice.

This standard coke or carbon per ton can be used by the Cost Department in comparing actual to standard costs. Management also uses this figure to judge operating supervision.

Each of the above classifications was then listed according to the calendar month of production. It had been the practice at the furnace to record temperatures and relative humidity readings for 12 midnight and 12 noon each day the unit was in operation. These readings were taken at the point of intake of the blowing engines. Because of similarity and in order to reduce the number of standards required, data were classified in three groups of months.

1. Winter

December	) 2.16 average grains of moisture per cubic foot of
January	) air. (32°, 90% relative humidity, 27 grains of
February	) moisture per pound, 12.5 ft. of dry air per pound)

2. Spring and Fall

March	) 3.88 grains of moisture per cubic foot of air.
April	) (60°, 70% relative humidity, 50 grains of
May	) moisture per pound and 13.25 cubic feet of dry
September	) air per pound)
October	)
November	)

3. Summer

June	) 12.01 grains of moisture per cubic foot of air.
July	) (90°, 80% relative humidity, 180 grains of moisture
August	) per pound of air and 14.5 cubic feet of dry air per
	) pound)

The exact situation that obtains at the tuyeres is not clearly defined. It is known that the temperature is sufficient to disassociate the water into its component parts. Yet it is known that farther up the stack some of the hydrogen particles attach themselves to the oxygen in the iron ore to form water again. However, hydrogen is found in the flue gases, indicating that not all of the hydrogen is converted to water. While the reaction at the tuyeres is endothermic, the reverse operation farther up the stack is exothermic. If all the hydrogen were consumed, the net result would be no gain or loss in heat. Yet the disassociation of the water takes place at the tuyeres where a slight loss of heat is important. The return of the heat higher up the stack aids the smelting process less than the disassociation of water at the tuyeres retards the action.

One grain is equivalent to .000143 pounds ($\frac{1}{7000} = .000143$)

For each grain of moisture in the air, 5954 pounds of water will be blown into the furnace in 24 hours. (.000143 pounds of water per cubic foot of air x 42,337,000 cubic feet of blast).

During fall and spring there are 1.72 more grains of moisture than in winter (3.88 - 2.16 = 1.72). Thus, 10,240 pounds (1.72 grains x 5954 = 10,240) more water will be disassociated each 24 hours.

During the summer there is an average of 10.25 more grains of moisture than in winter. Thus, 61,028 (10.25 grains x 5954 = 61,028) pounds more water must be disassociated in the summer.

From the equation $H_2O + C = H_2 + CO$, it appears that 2/3 of a pound of carbon will be consumed for each pound of water disassociated.

The coke required for this endothermic reaction is:

(fall and spring)	10,240 pounds of water x 2/3 = 6827 pounds of carbon per 24 hours
(summer)	61,028 pounds of water x 2/3 = 40,685 pounds of carbon per 24 hours

This carbon must be burned, though no pig iron will be produced as the result.

Actually, the ineffective use of that amount of carbon is not the most serious loss. Sufficient additional coke is added to the burden to disassociate the water. When the atmospheric humidity changes quickly and radically, the burden contains the wrong proportions and "off-grade" iron will result. Experienced and diligent workmen can recognize this condition and can introduce measures to minimize the ill effects. Prompt and decisive action will usually prevent "off-grade" casts.

Management should, upon acquaintance with such losses, institute proceedings to eliminate them before incentive application. Where this is not practical, such losses must be allowed in the standards, yet included in such way that management and supervision will constantly be aware of their existence.

As the direct result of these standards, the company later air-conditioned the blast in both furnaces.

Labor

Throughout this discussion we have pointed out numerous ways in which labor can affect furnace production. It was anticipated, and later borne out by experience, that labor's influence was adequately compensated for in the application of wage incentives.

Recapitulation

In summary then, the specific factors determining production are:

1. Ability to burn 655,200 pounds of carbon (728,000# x 90% in 24 hours)

2. Necessary loss of 6827 to 40,685 pounds of carbon to disassociate the water in the blast

3. A carbon consumption per ton, of

   a. 180# per ton of scrap iron
   b. 1620# per ton of basic iron from ore
   c. 1795# per ton of foundry iron from ore

4. Labor, whose influence for 100% production will be purchased by wage incentives

The formula for computing standard production can be expressed:

$$\frac{655{,}200\# \text{ of carbon} - N}{Z\# \text{ carbon} \times (100 - Y) + 180\# \text{ carbon} \times Y} = \text{standard tons per 24 hours}$$

N = pounds of carbon lost through disassociation of water

a.	Winter operation	N = 0
b.	Fall and spring operation	N = 6827#
c.	Summer operation	N = 40,685#

Z = carbon per ton for various grades of iron

a. 1620# for basic iron
b. 1780# for foundry iron

Y = percent of finished product made from scrap iron

Thus, for basic iron made from 15% scrap iron in the spring, the formula becomes:

$$\frac{655{,}200 - 6{,}827}{1620\ (85\%) + 180\#\ (15\%)} = \frac{648{,}373}{1377 + 27} = \frac{648{,}373}{1404} = 462 \text{ long tons}$$

The actual carbon per ton, for control purposes, however, is

$$\frac{655{,}200\# \text{ carbon burned}}{462 \text{ tons of pig iron}} = 1418 \text{ pounds carbon per ton}$$

For industrial use, a chart would be developed showing the standard tons, and the standard carbon per ton, per percentage of scrap ranging from 0 to 25% per each grade of iron produced and for each classification of humidity desired. These charts will not be included here, as they would not add particularly to this work.

Should the hot blast be air-conditioned, the basic carbon per ton should be reduced in proportion to the moisture content of winter air and the conditioned air. This would reduce the number of charts necessary to one for each grade of metal produced.

CHAPTER VI

THE WAGE INCENTIVE PLAN

The Bedaux system presumes that the normal amount of work in a task can be measured. The Bedaux unit of measurement, the B, represents the amount of work a normal person can produce in one minute, working at a normal rate of speed, under normal operating conditions and availing himself of a normal amount of rest time, provided he is not handicapped by the equipment or process. By a normal person is meant one who has the basic aptitudes and experience for the proper performance of a specific task. It is further assumed that the base wage pays for a normal amount of work, or 60 B's per hour. If the workman chooses to work faster than normal or to consume less than the allotted time for rest or develops greater than normal skill, he can and will produce in excess of 60 B's per hour. Bedaux contends that under the proper conditions of skill, effort, supervision, etc., a good workman can maintain a pace of 80 B's per hour. An incentive wage is paid for B's produced in excess of 60 per hour.

In the standard Bedaux application the wage incentive plan is designed primarily to increase the effectiveness of labor. This type of wage incentive lends itself admirably to assembly and small machine work where the cost of labor is relatively high. Labor costs in a blast furnace, while important, do not hold the same significance as other controllable items of cost. As mentioned before, a continuous flow of uniform quality product is essential to a successful blast furnace operation. This implies that every function of management and labor must be performed with precision and dispatch. Labor must be able and available to perform its duties on instant notice lest hundreds, possibly thousands, of dollars be lost. Therefore, the normal Bedaux application was modified to emphasize equipment performance instead of labor effectiveness.

The Industrial Engineering Department proposed to measure the labor content of blast furnace work and present the values, totalled by natural work groups, in three categories, viz.:

1. Tasks of a daily routine nature
2. Tasks performed regularly but not necessarily each pay period
3. Tasks performed with no regularity

The values in Group 1 were to be converted into work units per long ton of product for each grade of pig iron and condition of furnace operation. The values in Group 2 were to be expressed in terms of group work units per task and allowed upon written approval of the furnace turn foreman. The values in Group 3 were to be expressed in terms of group work per task and allowed upon written approval of the furnace turn foreman, countersigned by the superintendent. Management approved this plan in principle and the studies were begun.

Blast furnace operation required continuous study for considerable periods of time in order that all jobs be measured and prorated accurately. The Time Study Section was assigned to each of three eight-hour shifts, and a continuous study of each unit of the blast furnace operation was made for periods ranging from twenty-four hours to two weeks. Everything each member of the work group did was measured and recorded. After the study was completed, each time study man "worked up" and summarized his own studies. The chief time study man then summarized all of the time study data on a Master Study Sheet. Following this, all the men engaged in the study analyzed these data and discussed possibilities for improvement, with the recommendations for changes going immediately to the supervision of the furnace.

By successive stages each group in the blast furnace department was studied and the data analyzed, using the same time study men because of their familiarity with the work performed by the other groups. As the time study data accumulated, suggestions for the transfer of jobs and parts of jobs from one group to another increased. The studies showed quite clearly that no group could be expected to work at the desired 80 Unit-hour rate for the entire eight hours. The studies showed also that for several periods each turn whole groups worked at or near the limit of their ability.

The four groups, each closely associated with furnace capacity, were first established. They were as follows:

(Table on next page)

Table I - Blast Furnace Labor Groupings

Job Title	ORIGINAL GROUP No. of Turns	No. of Men	Total per 24 hrs.	NEW GROUP No. of Turns	No. of Men	Total per 24 hrs.	General Duties
Group No. 1 - Front Furnace Group							
Furnace tender	3	1	3	3	1	3	Make runners
Furnace tender helper	3	1	3	3	1	3	Clean up after cast
Runner maker	3	1	3	0	0	0	Remove slag & iron
Laborer	3	1	3	0	0	0	Change stoves
Stove tender	3	1	3	3	1	3	Observe furnace & stoves &
Stove tender helper	3	1	3	3	1	3	make necessary adjustments
Total			18			12	
Group No. 2 - Bottom and Top Filler Group							
Bottom Fillers	3	5	15	3	3	9	Get materials & weigh char-
Weighman	3	1	3	3	1	3	ges, fill furnace with ore,
Top fillers	3	2	6	3	2	6	scrap, coke & limestone
Total			24			18	
Group No. 3 - Blowing Engine Group							
Blower engine operator	3	1	3	3	1	3	Maintain and operate
Blower engine operator helper	3	1	3	3	1	3	blowing engines
Total			6			6	
Group No. 4 - Maintenance Group							
Pipe fitter	3	1	3	0	0	0	Daily inspection
pipe fitter helper	3	1	3	0	0	0	Lubrication, etc.
Electrician	3	1	3	0	0	0	Routine & minor repairs
Electrician helper	3	1	3	0	0	0	to all equipment. Fire
Millwright	3	1	3	3	2	6	and maintain the
Millwright helper	3	1	3	3	2	6	boilers. Added duties:
Electrician	1	1	1	1	1	1	and and all repair jobs
Electrician helper	1	1	1	3	1	3	the group could do.
Carpenter	1	1	1	3	1	3	
Boiler tender	3	1	3	3	1	3	
Boiler tender helper	3	1	3	0	0	0	
Laborer	3	2	6	3	1	3	
Total			33			25	

In addition, there were four miscellaneous or minor groups, namely:

Table II - Blast Furnace Labor Groupings

Job Title	ORIGINAL GROUP No. of Turns	ORIGINAL GROUP No. of Men	ORIGINAL GROUP Total per 24 hrs.	NEW GROUP No. of Turns	NEW GROUP No. of Men	NEW GROUP Total per 24 hrs.	General Duties
Group No. 5 - Pig Casting Group							
Pig casting machine operator	3	1	3	3	1	3	Receive hot metal; cast pig iron - load into freight cars; clean up and patch ladles.
Pig casting machine helper	3	1	3	3	1	3	
Laborer	3	2	6	3	1	3	Added duties: all repairs & relining of ladles.
Total			12			9	
Group No. 6 - Raw Materials Group							
Trestleman	3	2	6	3	2	6	Load raw materials into hopper cars; dump cars into bins on trestle
Laborer	3	1	3	0	0	0	
Steam shovel operator	1	1	1	1	1	1	
Steam shovel fireman	1	1	1	1	1	1	
Laborers	3	1	3	1	2	2	
Total			14			10	
Group No. 7 - General Labor Group							
Labor leader	1	1	1	0	0	0	General labor work whereever needed; most duties were assumed by Group 6 although some were given to various other groups
Laborer	4	1	4	0	0	0	
Total			5			0	
Group No. 8 - Ore Unloading Group (summer only)							
Car punchers	1	2 to 25	2 to 25	1	2 to 9	2 to 9	Unload cars of iron ore

The essential changes from previously accepted groupings are as follows:

1. The personnel and functions of the stove tender group transferred to the front furnace group
2. The personnel and functions of the trestlemen transferred from the bottom and top filler group to the raw materials group
3. The personnel and functions of the boiler group transferred to the maintenance group
4. The functions of the general labor group transferred to the raw materials group

Management was convinced on the basis of the first studies that the above changes and groupings were feasible, and directed that the organizational changes be made.

Current with the change, additional studies were made to assist the employees to make the adjustment and to secure additional data. The time study men were requested to take continuous studies of such nature that routine duties, performed regularly within the proposed pay period (one week), could be segregated easily from those duties performed irregularly or at regular intervals greater than the proposed pay period.

Thus, a measure of all routine work was established in terms of B's. The term "B" was later changed to "Unit", which is an equivalent unit of work.

All of the regular routine tasks with B or Unit values assigned were described in a Standard Practice Bulletin (S.P.B.) for each group and totalled. These totalled group values for regular routine work were then expressed in B's per ton of acceptable product (Groups 1, 2, 3 and 4). This is, of course, a deviation from the principle of work measurement but is a convenient form and seemed accurate enough for practical purposes. The routine values for Group 5 were expressed in terms of B's per ton of pig iron produced, while values for Group 6 were expressed in terms of B's per car of a standard weight of various materials loaded and dumped. Each special job was also listed and described with detailed assigned work values. In the case of each special value, a notation was included stipulating the conditions under which this value could be assigned to the group.

Total values, representing the amount of labor performed for a pay period for each group, then, can be calculated by multiplying the routine values for the grade of pig iron times the tons of production plus the sum of the values for extraneous work. Following normal methods, the B-hour or Unit-hour, which is the basis for wage payment, can be calculated by dividing the total accrued B's or Unit values by the total man hours used in earning the accumulated values.

Sample calculation - Group 1:

One week's production - 3280 long tons

1. Routine units per ton (from chart) 6.53x3280 =		21418 units	
2. Groups 2 and 3 work units totalled		5462	"
	Total	26880	"

Total group man hours - 672 for the week
True Unit-hour = 26880 units ÷ 672 man hours = 40 true Unit-hour

In most industrial jobs there is a certain amount of lost time, unavoidable, which must be accounted for in the standards. Unit values contain no credit for enforced idle time. The method usually employed involves adding a separate process allowance each pay period to the effective accumulated man minutes by the following basic formula:

Pay Unit-hour = 60 + $\frac{1}{4}$ true Unit-hour

The accumulated man minutes divided by the actual group man hours produces an average effectiveness called the true Unit-hour. The above formula can be developed as follows:

Assume that all of the idle time is enforced idle time and, therefore, the workmen should not be penalized for not making effective use of 60 minutes each hour. Since 80 units of effective work can be earned in 60 fully utilized minutes, each unit of work can be performed in 3/4 of a minute. Therefore, the length of time it takes to produce any true Unit-hour is 3/4 of that Unit-hour.

Working time = true Unit-hour x 3/4 (1)
Idle time = 60 - working time = 60 - 3/4 true Unit-hour (2)

If we assume that all idle time is chargeable to management, the total credit due the workman or pay Unit-hour is

Pay Unit-hour = true Unit-hour + idle time
= true Unit-hour + 60 - 3/4 true Unit-hour (from 2)
= 60 + 1/4 true Unit-hour (called Chart A2)

This provides very little monetary incentive, as shown by the following chart:

Table III - Process Allowance Chart

True Unit-hour	Pay Unit-hour	Idle Time per Hour	Premium Units per Hour
(A)	(B)	B-A	
0	60	60	0
20	65	45	5
40	70	30	10
60	75	15	15
80	80	0	20

Notice that increasing from complete idleness to 80 units per hour the premium increases only 20 units. The increase in premium is not at all in proportion to the work, and the most important item, production capacity, is not tied into the incentive. The difference between the pay Unit-hour and the true Unit-hour is totalled, evaluated in terms of actual dollars cost and presented to supervision and management for control purposes as an excess cost of production.

The formula was then arranged to create a greater incentive for capacity attainment. The normal point values are allowed on the same basis, i.e., tonnage, as are the standard capacity minutes. Thus, the true Unit-hour is already proportional to the capacity attainment. Therefore, if we multiply the first factor, 60, by the percent capacity, the entire pay Unit-hour is directly proportional to capacity attainment. Pay Unit-hour = 60 x 0/0 capacity + 1/4 true Unit-hour (called Capacity Chart A2)[3]. The formula is very flexible and has many beneficial factors, such as:

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[3] Chart A is 40 + 1/2 true point hour and Chart A1 is 50 + 3/8 true Unit-hour. These are used for varying degrees of labor's responsibility for enforced idle time. These three charts were basic formulas of the Charles E. Bedaux Company. Capacity Chart A2 was developed by the author and Giltner R. Ingles, Vice-President of the Charles E. Bedaux Company, for use in this application.

1. Provides greatest incentive for high capacity performance
2. Offers an incentive to assume additional duties provided the extra work done does not lower capacity attainment
3. Presents valuable data for labor control
4. Permits comparison of supervision
5. Shows management where additional engineering work might increase labor effectiveness

The following chart is included to illustrate the comparison of values obtained by using Capacity Chart A2 and Chart A2. Assume 40 true Unit-hour at 100% of capacity:

Table IV - Comparison of Process Allowance Charts

		CAPACITY CHART A2		CHART A2	
0/0 Capacity	True Unit-hour	Pay Unit-hour	Premium Units per Hour	Pay Unit-hour	Premium Units per Hour
80	32	56 (60)	0	68	8
90	36	63	3	69	9
100	40	70	10	70	10
110	44	77	17	71	11

Assume now that this group performed extra work and the result was a 44 true Unit-hour for the pay period at 100% of capacity. Thus, 60 x 100% + 1/4 (44 true Unit-hour) = 71 pay Unit-hour. In this instance, the premium was increased the same proportion as the work (10%). However, had the additional work resulted in lowering the capacity performance of the furnace to 95% the result would have been 60 x 95% + 1/4 (38[4] true Unit-hour + 4 additional units per hour) = 67.5 pay Unit-hour or a loss of 3.5 premium units per hour to the workman instead of a gain of one unit per hour.

Workmen are thus encouraged to assume additional duties when it will increase their labor effectiveness without reducing production.

Groups 5, 6 and 8 could scarcely affect the productivity of the furnace so the Capacity Chart A2, utilizing furnace capacity, could not be justified. For the sake of uniformity, it was felt desirable to apply some form of

[4] Unit values granted for routine work vary on the same basis as do the capacity standards.

Chart A2. These workmen were scattered all over the area and had practically no supervision, and since Chart A2 would provide bonus under all conditions of operation, it therefore would not provide the desired incentive. Again Chart A2 was modified, this time by a restriction of the maximum allowable process allowance or idle time minutes to the amount granted by Chart A2 when a normal crew was employed and the normal amount of work was performed. For purposes of illustration, we shall again assume a situation where a normal group performing its normal or slightly above normal amount of work should produce a 40 Unit-hour. By simple arithmetic then, each individual would have 30 minutes of enforced idle time each hour (40 units x 3/4 = 30 minutes of work at an 80 Unit-hour; 60 minutes per hour - 30 minutes of work = 30 minutes of enforced idle time). Thus, we would establish a limit of 30 minutes enforced idle time per hour and designate the process allowance chart as Chart A2 (limit of 30 minutes). Should the amount of work vary, as it frequently does, the resulting pay Unit-hour would vary as shown below:

Table V - Comparison of Process Allowance Charts

	CHART A2		CHART A2 (Limit of 30)	
True Unit-hour	Allowed Idle Time	Pay Unit-hour	Allowed Idle Time	Pay Unit-hour
0	60	60	30	30 (60)
20	45	65	30	50 (60)
30	37.5	67.5	30	60
32	34.0	68	30	62
36	33	69	30	66
40	30	70	30	70
60	15	75	15	75
80	0	80	0	80

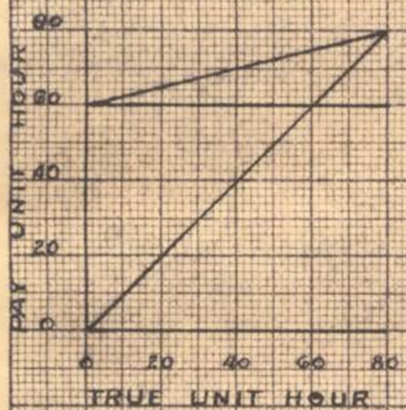
Normally, the limits are imposed in steps of five minutes (5, 10, 15, 20, 25, 30, 35, 40, 45, 50 or 55). Each group's potential and actual productivity should be analyzed and considered carefully before establishing the limit to be applied. If the proper limit is imposed, the workmen are granted minute for minute for all enforced idle time and are provided with a direct incentive up to their probable rate of highest effectiveness.

A graphic presentation of the process charts discussed is given on the following page.

Form E-3

PROCESS CHARTS

CHART A2



CAPACITY CHART A2

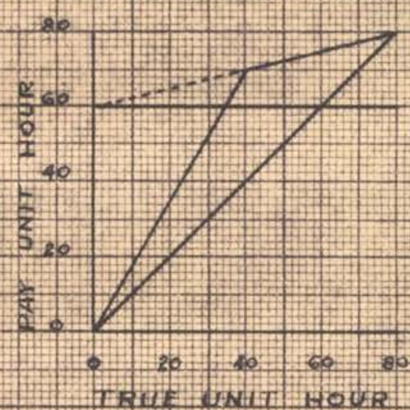


CHART A2 (LIMIT 30)

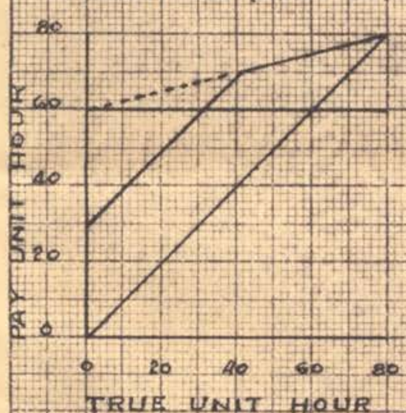
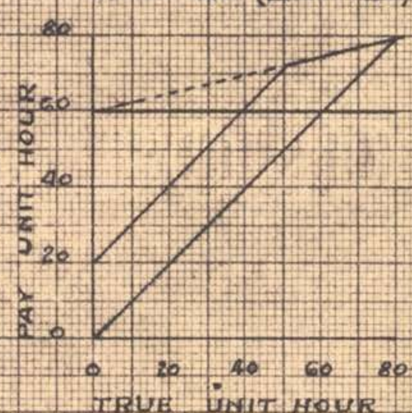


CHART A2 (LIMIT 20)



PREMIUM IS PAID FOR PAY UNIT HOUR PERFORMANCE ABOVE 60.

CHAPTER VII

CONCLUSION

The acceptance of these standards followed the usual industrial pattern; fair standards are accepted, though only after a satisfactory explanation and a fair trial. In this case, the reputation of the Industrial Engineering Department for trying to be fair and open-minded had quieted any real fears of drastic standards. Then, too, the changes in the personnel of the groups had already been made and found satisfactory. The workmen knew that their superintendent had cooperated in the development of the standards and had approved them step by step. The foremen cooperated in many ways to sell the plan, and the installation was accomplished without incident.

Shortly after the application, the workmen began to inquire as to how they could increase their group true and pay Unit-hour. The explanation resulted in the gradual elimination of the use of outside labor for special jobs. For example, when the company installed equipment to dry the blast air, the maintenance group requested that they be allowed to operate and maintain the equipment without adding to their force.

As the workmen accustomed themselves to the new routine and learned the importance of regularity in the performance of their duties, production not only increased but off-grade casts were practically eliminated.

Thus, the wage incentive plan accomplished the desired results of a greater quantity of more uniform quality pig iron at a lower cost as well as more accurate cost and production scheduling data.

It is very unlikely that these standards could be applied to another blast furnace, even one of the same design and size. However, the principles and techniques employed could be used with any furnace and were used in the incentive application to the remaining unit of the Division.

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