Productivity Measurement in a Welding Shop

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Introduction

Productivity, in general, reflects the output with relation to a given input and the implied conditions of input. Its measurement with reference to a welding shop presents peculiar problems. These problems pertain to the measurements of both input and output. Specifically, the measurement of output, development of norms of work measurement, and the effect of various input parameters on output generated in a welding shop, require a dealing different from those followed say in a conventional machine shop.

This paper discusses problems of productivity measurement and suggests means and methods to carry out the same. Productivity indices, as ready reckoners are also proposed. The coverage is confined to a welding shop consisting of conventional manual and semi-automatic welding equipment engaged in engineering industry, using techniques of medium and large size batch manufacture.

Work Content Involved

Compare a welding shop with a medium size general purpose machine shop. In such a machine shop, as each machine is operated by an operator, the methods can be defined and standards can be established for individual operations with a fair degree of accuracy. The feed back on output for each period can be easily obtained and operator performance and shop productivity easily established for a given interval of time. In a welding shop this is not the case. Working methods are not so well defined: groups of people work on a job, machine work is combined with manual work.

A typical well organised medium size general purpose welding shop consists of a blank preparation section (consisting of shearing, gas cutting etc.) an assembly section where parts are tack welded and a welding section where full welding is carried out on the assemblies and other sections. There is further provision for post weld operations, like dressing, flux removal etc.

While measurement of productivity where machines are involved is straight forward and easy, the input being measured in machine hours and the output expressed also in so many standard hours, welding operations present problems and require a different approach. The foremost problem lies in selecting a suitable unit of output.

Units of Output

The number of physical units produced should be by far the easiest unit of output. It has other advantages as well. It is easily comprehensible. It is easily accountable and no complicated calculations involving a knowledge of statistics are involved.

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However, there are severe limitations. In a shop with a hetrogenous mix of a range of products, subassemblies and parts to be fabricated, the ouput measured in terms of physical units produced, may not convey the information, we are after. The objective, afterall, is to obtain a coherent output from a shop, a work centre from a workman and to correlate it with input to obtain productivity.

Expressing the output so generated, in terms of weight units such as total Kgs. or tonnes produced, although easy to account for and to report, has also limitations. The weight of the output, for example, does not give any indication of the comparative complexity of fabrication involved between one job and another although both may have the same weight. Equal output so reported in these cases, when correlated to different inputs depending on the extent of work required, will present a false picture of productivity.

In many establishments, the practice of expressing output in terms of weld lengths produced is followed. This concept has also the problem of comparison of weldments on different thicknesses of materials. Besides, the type of joint and weld position play an important role in affecting the output. This problem has been attempted to be sorted out through the help of use of correction factors to arrive at equivalent weld lengths adopting a particular joint configuration and the weld position as the standard base.

However, even with this sophistication which obviously involves a lot of calculating work, this concept has limitations wherever the work involved in fabrication also calls for a large measure of fitting, assembly, dressing, rivetting etc. Usually such type of work in a welding shop is taken as work incidental to welding and gets reflected in indirect work (overhead work) and hence does not appear as quantified output in absolute figures. But for jobs, where these type of activities are substantial, a different type of approch involving the measurement of this incidental work as also the output, is necessary.

A more scientific way is to evaluate the output in terms of standard hours produced. This should cover both the 'arc-on' type of work i.e. pure welding time, as well as the non 'arc-on' type of work which is, depending on individual cases, desired to be measured as output.

Although sometimes an exercise of this type calls for elaborate calculations, it has clear advantages of being methodical and logical and it can encompass in the output measurement all types of work. The chief advantage lies, however, in the fact that because the 'input' is also in the same units, it is easy to express the output as a ratio of the input and thus obtain a real measure of productivity.

Evolving Work Standards

Welding time as an output, can be categorized basically as.

(a) Pure welding time—'Arc-on' time
(b) Incidental
(c) Relaxation and personal allowances

(a) Pure Welding Time

This is essentially the time during which the metal is being deposited after the arc has been stuck. Of the total time involved in carrying out a welding job, 'Arc-on' time forms a key factor in determining the productivity.

Its Measurement

In developed countries, 'arc-on' time can be straightaway measured with the help of an Arc Clock, while an actual job is being done.

However, analytical approaches are also possibile.

'Arc-on' or pure welding time is dependent on, basically,

(i) Property of the elctrode.
(ii) Welding current, its type and polarity.

The type of electrode used affects the welding time because of the particular composition of the core wire and the flux coating. The welding current to be used for an electrode is determined by the size of the electrode as well as by the characteristics of the electrode suitable for the parent material, its core wire, flux coating and its suitability for the specific working position. Beyond a certain maximum current, the electrode can get red hot and produce porous and defective welds. Similarly, lower than desired currents will result in improper fusion and less penetration.

For a type of electrode, it should therefore be possible to create a 'Norm' to represent a measure of melting or welding time.

This is usually referred to as the "Co-efficient of fusion" and is the amount of metal in grammes which will be deposited in one hour of arcing with a current density of one Amp.

Usually, this data can be obtained from the manufacturers of electrodes. However, even in a workshop, it is not difficult to determine this co-efficient.

$$\text{Co-efficient of fusion, } f = \frac{W1 - W2}{A \times M} \times 60$$

where W1 = Weight of job before welding
W2 = Weight of job after welding
A = Amperage used
M = Arc-on minutes

For a particular section of the weldment the metal deposited can be calculated and is defined as:—

$$G = F \times L \times S \ldots\ldots\ldots (i)$$

where G = Metal deposited in gms.
F = Area of cross section of weldment, in sq. cm.
L = Length of weldment in cm.
S = Density of weldmetal in gms/cm^3

Also, the weight of metal deposited can be obtained from the formula:—

$$G = \frac{f \times I \times To}{60} \ldots\ldots\ldots\ldots (ii)$$

Where I = Welding current in Amps.

To = Pure welding or 'Arc-on' time in minutes.
f = Co-efficient of fusion of electrodes in use, in gms/Amps. hour.

Equating, the equations (i) & (ii)

$$F \times L \times S = \frac{f \times I \times To}{60}$$

From the forgoing, To, the pure 'Arc-on' time can be obtained, as all other data are known.

Alternative Approach

To make the calculations simple and easy to use, it is generally desirable to determine first the number of electrodes *n* required for a length L of the weldment of cross section F.

If, d = cross sectional area of electrode,
l = usable length of the electrode, obtained by deducting the throwable stub length from the full length of electrode
S = Density of the metal to be deposited,

$$F \times L \times S = n \times d \times l \times S$$

$$\text{or } n = \frac{F \times L \times S}{d \times l \times S} = \frac{F}{dl} \times L$$

(based on 100% deposition efficiency)

For a given set up of a weld joint, F can be predetermined. Similarly, dxl is constant for a particular size of the electrode. It is, therefore, possible to create standard reference sheets for each joint preparation to provide an easy reckoner to determine the number of electrodes required for a desired length of weldment.

Pure 'Arc-on' time, is therefore,
To = *n*×melting time per electrode

Melting time per electrode is basically dependent on:—

(a) Dia of the electrode wire
(b) Type of electrode
(c) Welding current, its type and polarity
(d) Working position

Although various electrode manufacturers do provide this data ie melting time of an electrode, it is preferble that the user develops this data in his own workshop taking into account the prevalent actual conditions available in the shop.

In the above analysis, it has been assumed that 100% of the weld deposit is available from the electrode wire. Or, in other words one gramme of electrode wire generates one gramme of weld deposit. This is however, not generally true. There are spatter losses and inevitable burning of some portion of the welding wire during the process of welding. Net metal deposited therefore gets reduced.

In some other cases, weld deposit receives material from the flux coating, so that net metal deposited stands increased.

It is, therefore, necessary to take these aspects of deposition efficiencies of electrodes, as claimed by different electrode manufacturers, while arriving at the actual requirements of electrodes.

If deposition efficiency is E, actual number of electrodes, $N = \frac{n}{E}$

A typical compilation sheet showing the use of above technique is shown under Table—1.

Semi Automatic Processes

In semi-automatic processes employing the techniques of SAW, MIG or MAG, where the speed of welding is controlled by mechanising the wire speed, obviously a different approach is necessary to arrive at the pure welding time.

Robert R. Schaefer (1) refers to the use of the following relationship at Heil Co. Milwaukee, Wisconsin (U.S.A.).

$$\text{Arc time per unit length of weld} = \frac{\text{Fillet Area}}{\text{Wire area} \times \text{wire speed} \times \text{PE}}$$

where, PE = Process Efficiency factor

For a given application, the fillet area and the efficiency factor are constant, so that

$$\text{Arc time} = \frac{(\text{Fillet area})}{\text{PE}} \times \frac{1}{\text{wire area} \times \text{wire speed}}$$

$$= \text{Fillet factor} \times \frac{1}{\text{wire area} \times \text{wire speed}}$$

Tables can be constructed to present fillet factors. for a given application of process with relation to different wire size as

$$\text{Arc time per unit length} = \frac{\text{Fillet factor}}{\text{wire speed}}$$

(b) Incidental Times

These include all other time consuming operations which are incidential to 'Arc on' time. Such operations are usually, electrode changes, slag removal, tack removal, setting of welding machines, change of work position, dressing of weldments,gouging etc. and depend on the practices followed in a particular shop. In many shops, a welder carries out these operations as a regular practice, whereas in others, some of these operations are left to be performed, by helpers, dressers, etc. and form a part of the total indirect (over head) work.

Usually, the extent of incidental time is determined through time studies of elements and by analysing the data so collected to build time estimates through synthesis.

In case, such a sophistication is left uncalled for the incidental timings can be expressed as a percentage of the 'Arc on' time. The percentage to be used is determined through well conducted work sampling studies.

A typical compilation sheet showing some of the elements to be considered to arrive at incidental time estimates is shown in Table-II.

(c) Relaxation and Personal Allowances (R & P)

As for other time standards, like for machine shop operations etc. allowance provision is made for rest pauses and other stoppages of work which become necessary for human needs.

The total standard time for welding thus is the total of pure welding time, incidental time, and the R & P allowance.

To this may be added other allowances such as contingency etc. followed as practices in a company.

Non repetitive Jobs

There are occasions when one encounters a situation wherein due to the jobbing nature of work, the operations are not well defined and separated (such as blank preparation, assy, welding etc.) In such jobbing type of shops, a group of people are engaged in the production process—everyone doing every operation as felt necessary. The operation in fact is "complete manufacturing of the item".

In such cases also, it is necessary to know the level of productivity of this large group of persons, though it may be uneconomical to measure the same by time study/synthesis. These are the cases wherein use of statistical theories on correlation & regression come to help.

The jobs are built up of a number of parts of varying dimensions which have been fabricated prior to final assembly carried out through welding. Varied joint configurations and types of fillets involving different work positions are also inherent. Yet, depending upon the product and the type of product mix in a workshop, it should be possible to discover and identify a certain relationship amongst these jobs to form a group of these jobs. This relationship can exist to envelope some of the following attributes.

(a) Weight
(b) Number of pieces
(c) Overall dimensions
(d) Length of structural members

TABLE I

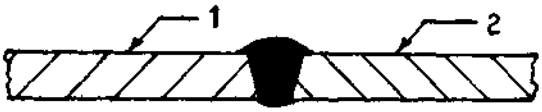
TIPICAL REF. DATA FOR BUTT WELDING

Thickness mm.	Weld area* mm²	No. of layers	Electrode dia mm.	Arc on time Minute/Mtr.
6	28	1	5	6.2
8	45	1	5	10.2
10	67	2	5,6	12.5

***Reference : Spravochnik Normirovshika III**

'Arc-on' time compilation

Job Details : Butt weld 6mm. plate



Particulars	Fillet/plate size	Position	Layer	Electrode dia mm.	Weld Length Mtr.	Time/Mtr.	Total Time min.
Parts 1 and 2	6	H	1	5	1.5	6.2	9.3
—do— backside	—	H	1	5	1.5	2.0	3.0
							12.3

TABLE II

Incidental Time—Typical Elements

S. No.	Description	Base time	Freq	Time in min.
1	Change electrode and start welding	t_1	f_1	Bas × Freq.
2	Change position			
	a) Free movement	t_2	f_2	
	b) Constrained movement	t_3	f_3	
3	Load/Unload parts	t_4	f_4	
4	Overturn job	etc.	etc.	
5	Change current			
6	Change voltage			
	Total incidental times	—	—	—

t_1 t_2......tn = Time estimates arrived through time studies.

f_1 f_2......fn = Frequency of occurence of the relevant base time t_1 t_2...tn.

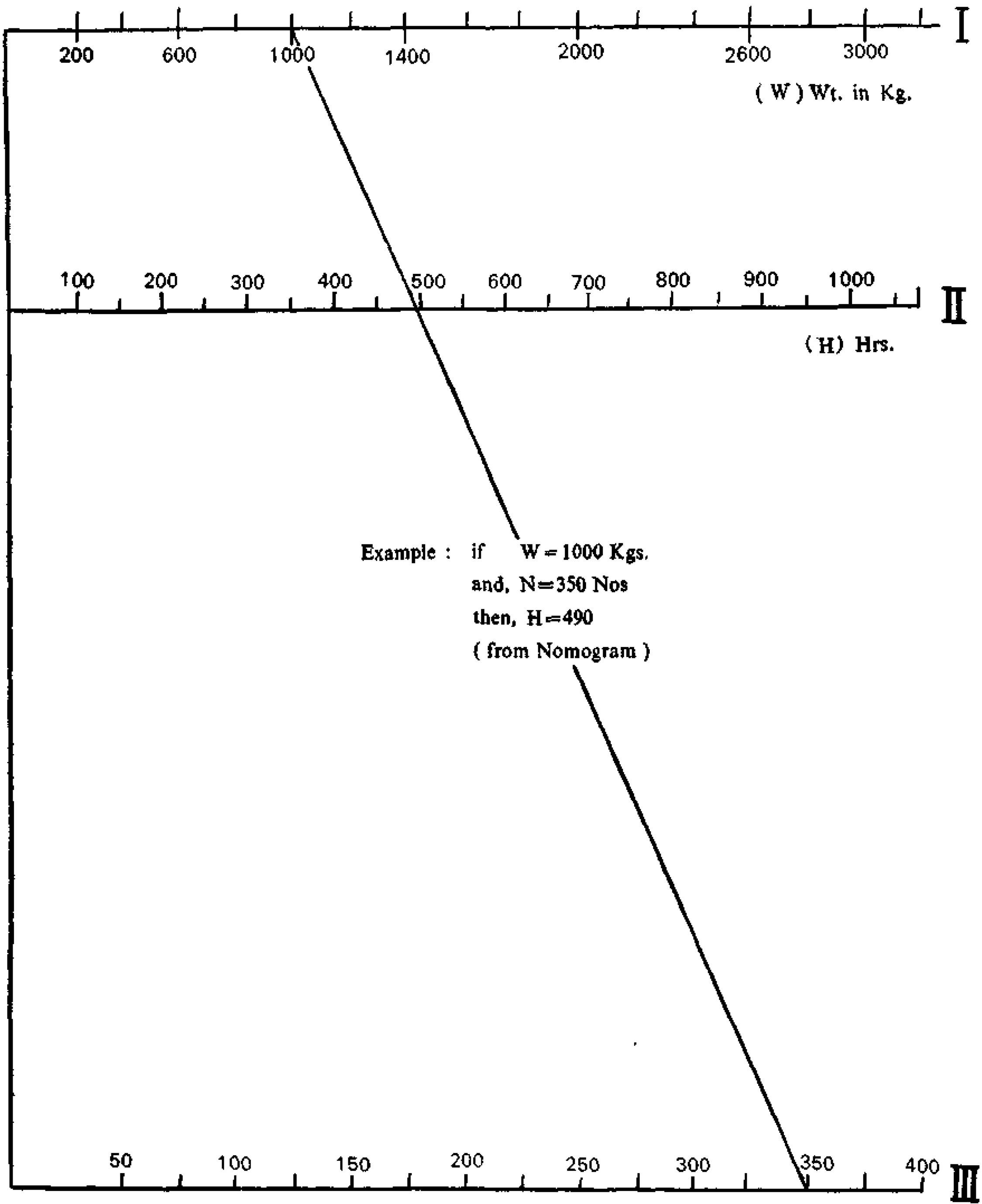
Time in Minutes = Base time × Frequency.

EXHIBIT 1

NOMOGRAM FOR COMPUTING

$H = 0.252W + 0.61N + 23$

(For $60 \leq W \leq 3000$ Kg. & $20 \leq N \leq 400$ Nos)



Example : if W = 1000 Kgs.
and, N=350 Nos
then, H=490
(from Nomogram)

How to use the Nomogram :

A job calls for total weight. 1000 Kg

No. of parts involved are 350 Nos.

Mark a point representing 1000 Kgs. on Line 1 (at top) and join it with a point representing 350 Nos. on line III at bottom. Read the Hrs required (490) at the point of inter-section of this line with the centre line No. II.

Take for example a fabrication shop engaging some 20 people and manufacturing (one off) non repetitive jobs of various types—say jobs ranging from 10 kg. wts. to 2000 kg. involving a number of fabricated members. Historical records of the actual man/machine hours spent against such jobs are collected.

In the case cited above, for example, it may be possible to develop a statistical relation, relating the hours spent to the number of parts and weights in kgs., subject of course, to the existence of a significant multiple correlation coefficient, such as;

$$\text{Hours}=K_1\times(\text{No. of parts})+K_2\times(\text{wt. in kg})+K_3 \text{ (a constant)}$$

This requires collection of historical data covering a broad spectrum of jobs handled in the shop over a period of time. The data so collected should statistically be representative of the jobs calling for analysis. This data is further analysed to develop the relationship.

In an actual shop floor experience, calling for an analysis of this type, the authors of this paper, established the following relationship encompassing weight, number of parts and time consumed,

$$H=0.252\ W+0.61\ N+23$$

This exercise covered the range of,

Weight between 60—3000 kgs. and
No. of parts between 20—400

The multiple correlation co-efficient for the set of readings so used was 0.937 which is highly significant. It may be however, emphasized here that such correlation should not be directly copied down from text books/experiences of others etc. and should always be developed for a group of jobs under prevalent conditions of work in a workshop. There is also a necessity to recognize that the correlation will undergo drastic changes even within the same workshop depending upon how and when the input resources and conditions of work change. A change in technology or a change in methods used, for example, the holding devices, fixtures, can adversely affect the data for this analysis.

The linear relation so arrived at can also be represented through a nomogram. This helps in easy and quick reading of the time estimates of the jobs once their weights and the number of parts going into the job are known. This is of course valid only to such of the jobs which fall within the scope mentioned earlier. One such nomogram developed through the linear relationship cited above, is shown under exhibit 1.

Feed Back and Updating

Work standards evolved through any of the techniques discussed, require to be checked and their reliability verified against the actual feed back from the shops. This is all the more necessary for such standards which have been developed through synthesis of data collected from actual observations.

The objective is two fold.

(a) the reliability and accuracy of the work standards will instil confidence amongst the work force,

(b) the work standards can be updated depending upon the change in methods, techniques and modifications to existing working systems on the shop.

The feed back system requires a methodical and systematic approach to be developed so that information about the output, time spent on output, the conditions of output is available regularly.

Productivity Indices

The output generated can be converted now to standard hours produced, and this can be used to determine the productivity Index, P.I.

$$PI = \frac{\text{Standard Hours produced}}{\text{Actual Hours Taken}}$$

PI for a particular job or for a particular day may not be the representative PI of the workman, group of workmen or of the shop. There is a need therefore, to collect the PI's and plot them against a time base so that a visible pattern or trend is discernible.

Conclusions

Norms and productivity indices are necessary for any systematic and methodical approach for improving productivity in a shop. For a welding shop, measurement of productivity requires a different approach. An attempt has been made in this paper to identify the problems of measurement of productivity in varying situations and guidelines indicated as to how to carry out the exercise of measuring output and correlating it to input.

References

1. Robert R. Schaefer 'Simplify your Welding Standards" American Machinist, OCT 1974.
2. Spravochink Normirovachika Vol III Mashgiz, MOSCOW.