

**A SURVEY OF PERFORMANCE RATING RESEARCH
IN WORK MEASUREMENT**

by

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B.E., Mechanical Engr. , University Of Madras, India, 1983.

A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department Of Industrial Engineering

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1988

Approved by:



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ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation and gratitude to Dr. S. Konz for his valuable guidance and encouragement throughout his study in this university.

The author is indebted to Dr. D. Grosh and Dr. R. Turnquist for serving on the graduate committee. The author is indebted to his parents without whose encouragement this graduate program may not have materialized. It is to them that this work is dedicated.

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1. INTRODUCTION

An important and difficult part of time study is to evaluate the speed, pace or the tempo (these terms refer to the speed of movement of operations and are used synonymously) at which the person is working during the study. The analyst must judge the operator's speed while the analyst is doing the time study. This is called rating.

Work measurement rating is important because the rating of operator performance was involved in normalizing performance time of most predetermined time systems as well as in time study. The rating factor accomplishes the adjustment of timed performance to make it representative of what "the average operator could achieve when working with average skill and effort."

ANSI Z94.12 [----, Sectional Committee Z 94, 1971] defines performance rating and related terms as follows:

Performance Rating: The process whereby an analyst evaluates observed operator performance in terms of a concept of normal performance.

Performance Rating Factor: The number (usually a percentage) representing the performance rating.

Performance Measurement: The assessment of accomplishments in terms of historical or objective

standards or criteria.

The establishment of a definition for normal or standard speed also has posed many problems. Some people consider "normal" as a kind of speed for non-incentive workers. Others took it for granted that normal was the speed to be maintained without "taking a rest." "Today 'normal pace' is defined as the 'effective' rate of performance of a conscientious, self-paced, qualified employee when working neither fast nor slow and giving due consideration to the physical, mental, or visual requirements of the specific job" [Maynard, 1956].

Before any rating procedure will permit the equating of one observer's time study values to that of another observer, a proper concept of normal must be established upon which all can agree. Both people must have the same concept of what constitutes normal performance.

One method of achieving this is pairing a novice and a veteran rater to study a variety of operations. A comparison of their ratings will show whether the novice has the proper concept of normal. The novice then can, with help of such comparisons and practice, adjust his mental concept to agree with that of the more experienced rater.

A better method is to utilize, by purchase or

rental, some of the performance rating films obtainable from the Society for Advancement of Management, universities, private industrial firms, or consulting engineering firms. The mere fact that a person is experienced is no guarantee for correct leveling. Rating films are excellent for training both the novice and the experienced time study analyst. The scheme of pairing then can be used as a supplement to these rating films if the experienced person has proven the ability to consistently level correctly.

One remaining method of achieving a normal concept has arisen since the use of MTM (Methods Time Measurement) has become widespread. This consists of standardizing an operation and setting a MTM rate on it; this time comprises the time required of a 100% operator before the addition of any time allowances. The stopwatch then will show accurately the true actual time, and, by division, the true performance level. This will enable a cross check of the performance rating made by either new or experienced time study analysts.

A second MTM approach to leveling is to establish one element of the study so that it includes the motions defined in a standard MTM motion category. The actual time taken by the operator to perform this element then can be compared to the MTM time to obtain a performance

rating of the operator for that element of the study. If the operator's consistency is average to excellent, it then would be reasonable to expect the regular time study rating of the operator to compare closely to this element rating.

At this point it is necessary to mention that extreme confusion exists in the terminology with respect to the various rating systems in use. For example, leveling is a term used by some as an alternate name for the Westinghouse system, by others as a general term for the process of rating. Pace rating is referred to by some as effort rating, performance rating or speed rating. Leveling is sometimes referred to as Skill and Effort rating. As with a number of other topics in work measurement, the analyst must clear the terminology air before intelligently using a rating system. Finally, all commonly employed time study rating procedures can be placed into two main groups.

1. Mathematical Rating.

2. Judgment Rating.

This report will study 1) the rating systems in vogue, 2) the establishment of various benchmarks for normal performance, 3) the factors affecting performance rating in time study, and, 4) training in rating with a view to improve observer accuracy.

2. WESTINGHOUSE SYSTEM

2.1 Introduction

One of the oldest and very widely used systems of rating is the one developed at the Westinghouse Electric Corporation; it was originally published in 1927. The need for full understanding and adequate training in the use of the technique in order to get consistent and accurate results, is strongly stressed. This system also is known as the LMS system, standing for Lowry, Maynard and Stegemerten [1940] who developed it at Westinghouse. The system gives numerical weights to skill, effort, conditions, and consistency as found during a study. The extent to which the variables affect the productivity of a worker help the analyst make a more precise total evaluation. This basic advantage of the LMS system should not be overlooked, even though "speed rating", wherein rating is based only on the speed at which a task is being performed, is simpler and more frequently used today.

It is important that the meaning of the four elements namely, skill, effort, conditions and consistency be understood prior to the application of the technique [Maynard, 1936].

2.2 Skill

Skill, defined as "proficiency at following a given method", can be explained further by relating it to craftsmanship, demonstrated by proper co-ordination of mind and hands. The operator's skill is determined by the operator's experience and inherent aptitudes such as natural co-ordination and rhythm. Practice will tend to develop skill, but it cannot entirely compensate for deficiencies in natural aptitude.

A worker is most capable of following directions (methods) when in excellent physical condition. Reflexes and other evidences of motor fitness are a gauge of the responsiveness of the nervous system, much as the sensitiveness of temperature controls are judged by the tolerance of the setting they will control. Natural aptitudes either may be beneficial or detrimental to successful action of muscles in a given task. Co-ordination, or the lack of it, may make the difference between a master craftsman or a duffer working with the same tools. The work analyst must, therefore, either fit the methods to the available human power or else recommend the correct human capabilities for a desired method.

The education and training of workers enter into the

problems of skill and its relation to work methods. Workers cannot be expected to perform skillfully on tasks which their background has not fitted them to do. Likewise, a watchmaker might well enthusiastically follow the set method for assembling a complex control device, but balk and procrastinate when expected to grind gates off rough castings. The skill of a worker must be complemented by the method to assure compliance.

There is a wide range of manual dexterity between the best and poorest individuals. Basic manual dexterity as a characteristic of an individual has been studied by many psychologists. Standard tests are available for measuring this aspect of the human machine.

Since skill involves manual dexterity most directly, it is logical to expect a skill ratio similar to the dexterity ratio in the worker population. However, the screening of applicants by employment departments, limitation of workers to appropriate job categories, normal attrition of layoffs and discharges which tend to reduce the number of poorer workers, and other personnel policies tend to reduce this range in industry. The skill ratio actually falls in about a 1.5 to 1 ratio.

Skill of the degree ordinarily met in industry has been classified in the Westinghouse system into six

categories. These are as follows:

1. Poor skill.
2. Fair skill.
3. Average skill.
4. Good skill.
5. Excellent skill.
6. Super skill.

To illustrate how further aids are improved in the Westinghouse system for judging this attribute, the guides for poor skill, average skill, excellent skill, and super skill are presented in Table 1.

2.3 Effort

The "work readiness", or willingness of an employee to expend energy in effective work, is a complex of human behavior worthy of close attention by industrial engineers. Historically, lack of this attention has been the root of many production floor problems, management difficulties, work stoppages, union frictions, and disastrous strikes. Management increasingly is recognizing its fair share in the problem of providing the psychological climate in which its personnel can and will put forth their best efforts. Much of the bargaining material with which unions deal concerns this factor of productive output.

Table 1

Attributes For Judging Skill

Poor Skill (Category 1):

1. Cannot coordinate mind and hands.
2. Movements appear clumsy and awkward.
3. Seems uncertain of proper sequence of operation.
4. Untrained on operation.
5. Misfit.
6. Hesitates.
7. Errors occurs frequently.
8. Shows lack of self-confidence.
9. Unable to think for himself.

Average skill (Category 3):

1. Self-confident
2. Appears a little slow in motion
3. Work shows effects of some forward planning.
4. Proficient at the work.
5. Follows sequence of operations without appreciable hesitation.
6. Coordinates mind and hands reasonably well
7. Appears to be fully trained and therefore knows his job.
8. Works with reasonable accuracy.
9. Work is satisfactory.

Excellent Skill (Category 5):

1. Self-confident
2. Possesses high natural aptitude for the work performed
3. Thoroughly trained.
4. Works accurately with little measurement or checking.
5. Works without errors in action or sequence.
6. Takes full advantage of equipment.
7. Works fast without sacrificing quality.
8. Performance is fast and smooth.
9. Works rhythmically and with coordination.

Super Skill (Category 6):

1. Naturally suited to the work.
2. The operator of excellent skill perfected.
3. Appears to be super trained.
4. Motion are so quick and smooth that they are hard to follow.
5. Work has machine-like appearance and action.
6. Elements of operation blend into each other.
7. Appears not to think about what he is doing.
8. Conspicuously an outstanding worker.

For a person to show best efforts, the person must be happy in the social sense. All of the people with whom the worker comes into contact, both at work and away, have an influence in this respect. Disappointing or frustrating social relations, whether of the brief or long-lasting type, are destructive of working effort. Carefree and satisfying activities with other people keep the worker attuned to the need and value of doing a fair day's work. Common courtesy between employees often makes the difference between good and poor effort in a factory.

Effort, the "work readiness" or drive of a worker to expend energy, is a variable which the operator can control at will. The effect on effort of various human attributes are not as great as generally supposed. Only a 25-to-30 % range between the slowest and the fastest workers was found attributable to effort alone by Lowry, Maynard, and Stegemerten. Naturally, slow workers (unless other human factors loom larger) tend to be eliminated whereas excessive effort by even the most conscientious worker cannot be maintained over long periods of time without harm.

As was done for skill factors, six ranges of effort were isolated and defined. The key characteristics

outlined permit ready reference and identification of the effort level. They are poor effort, fair effort, and again through to excessive effort. The good effort guide statements are:

Good effort (Category 4):

1. Works with rhythm
2. Idle time is minor or non-existent
3. Conscientious about work
4. Works at a good pace that can be maintained throughout the day
5. Actions indicate faith in time study observer
6. Readily accepts advice and solutions
7. Makes suggestions for improvement of operation
8. Maintains good order at workplace
9. Uses proper tools
10. Keeps tools in good condition

It is noteworthy that, while skill and effort are evaluated separately in this rating system, the levels of skill and effort tend to complement each other rather than being contrasting. Poorly skilled workers, attempting to compensate by excessive effort, usually interfere with what little skill they possess and this appears as fumbles, false starts and frustration. A highly skillful worker, however, appears to work with deceptive ease; every motion counts and produces useful effects on the workpiece. Operators with higher levels of skill can reduce their effort successfully without losing effectiveness. It is usual, however, for poor effort and poor skill to combine and for high skill and high effort to coexist when training has been adequate.

2.4 Conditions

The questions of effort and skill, as are readily apparent from the preceding discussion, largely revolve around human capacities and relationships. However, people also work in conditions or surroundings which, while not primarily composed of human factors, do have direct bearing on their productiveness. It is the responsibility of management to enhance the working environment in order that speed of motions may be maintained and improved. The important factor in the following conditions is not what their absolute value might be, but whether one condition or another is normal and the best that can be provided for the work being done. People will adapt themselves to an amazing range of conditions and react normally as long as they feel that humane and just consideration in adjusting those conditions has been taken by the management.

Conditions basically affect the sense mechanisms of the human machine. To adequately consider conditions thus implies that the impact of the surroundings on the sensual apparatus is involved. The senses of sight, sound, smell, and thermal comfort are amenable to a degree of control by changes in the surroundings directly, thus being affected by external or mechanical control.

Visual perception is aided by the correct kind and amount of illumination. Much expert data and advice on this subject are available. Reduction of distraction of the eyes can be achieved by shielding glare, drawing the sight of the worker to more important areas by effective work room design, and/or proper use of color.

The assault of noise on the ear can cause hearing loss often found among industrial workers. Dissonant, rasping, whining, or gruff sounds caused by the misuse of the public address system, say, should be offset by familiar sounds such as music played at intervals during the workday.

Thermal conditions also can effect worker efficiency and productiveness. The dress of workers often may be dictated by the temperature usual to their tasks. As such, extremes of heat and cold should be avoided.

Industrial conditions today are generally such that the great majority of time studies will be rated as involving good to excellent conditions-- and a few might even be rated ideal. A variation of 15 % is about the maximum that can be ascribed to the range between poor and ideal conditions.

Six classes of conditions have been given : poor, fair, average , good, excellent, ideal. The important aspect for the analyst to note is the relative departure from what are usual conditions prevailing in the work space concerned.

Effort and skill are attributes of the worker whereas the job conditions are external influences on output. The conditions rating factor have nothing to do with the method employed, propriety of tools used, sharpness of tools and similar considerations. Such matters are subjects for separate attention by managers. They relate specifically to tools and methods, having no relations to the concepts gaged as conditions in the leveling procedure.

2.5 Consistency

As is true of any series of numerical observations, the elemental times taken during a time study exhibit a variability that can be subjected to statistical analyses. Such variation has little to do with the operator, so long as the operator is giving average performance. Attempts by a worker to influence the time taken will result in inconsistent variation of the elemental times read from a watch. Thus the analyst must make an effort to reduce the effect of this ranging of

times on a standard.

According to the LMS system, the range of inconsistency for valid readings will not exceed about 8 % from low to high range. Six classes of consistency have been assigned to adjust for acceptable variations: poor, fair, average, good, excellent, and perfect.

The work analyst can best determine the consistency while summarizing the study away from the workplace. If no variations exist in the readings for each element, consistency is perfect; such times are very unlikely to be encountered often and the standard should be increased to recognize this fact. Process or machine controlled elements are the only ones in which perfect consistency is not unexpected.

Occasionally, serious variations in readings are found in study elements. These variations often are caused by non-repetitive or non productive events which a properly made study should include to permit adjustment of the standard. Another standard procedure is to strike out from consideration in the averaging of element times any readings that are obviously incorrect or are influenced strongly by extraneous facts, provided adequate reason is given. When judging consistency, the

nature of the work elements also should be considered. Simple operations tend to show less variations than complex operations.

The skill of the operator also should be considered. Highly skilled operators normally work more consistently than poor employees. Highly skilled operators tend to work with good or near perfect consistency unless they deliberately tend to show a poor performance.

2.6 Performance Rating Data

The rating factors for the LMS system are shown in Table 2. When the time study analyst is observing the operator, the analyst notes (with the code symbols) the skill, effort, and conditions for each element and/or the job as a whole. Later, when summarizing the study, a consistency rating is assigned. The numerical rating of the factors then is added algebraically to the nominal 100 per cent to produce a finished rating.

As an example of how the table is used, suppose a time study element was rated as B1-A2-C and a rating of B was assigned for consistency during the study summary. The combined rating for the element then is B1-A2-C-B for skill, effort, conditions, and consistency in that order. It is conventional to write the symbols in this order.

Table 2.

Performance Rating Data - Additive Percentage Values

FACTOR		SKILL	EFFORT	CONDITIONS	CONSISTENCY
Category	Code				
SUPER	A1	+.15			
	A	+.14			
	A2	+.13			
EXCESSIVE	A1		+.13		
	A		+.125		
	A2		+.12		
IDEAL	A			+.06	
PERFECT	A				+.04
EXCELLENT	B1	+.11	+.10		
	B	+.095	+.09	+.04	+.03
	B2	+.08	+.08		
GOOD	C1	+.06	+.05		
	C	+.045	+.035	+.02	+.01
AVERAGE	D	.00	.00	.00	.00
FAIR	E1	-.05	-.04		
	E	-.075	-.06	-.03	-.02
	E2	-.10	-.08		
POOR	F1	-.16	-.12		
	F	-.19	-.145	-.07	-.04
	F2	-.22	-.17		

The rating would result as follows:

B1 Skill	+0.11	(Excellent)
A2 Effort	+0.12	(Excessive)
C Conditions	+0.02	(Good)
B Consistency	+0.03	(Excellent)
	1.00	

	1.28	or 128 %

Note that the maximum combination of skill and effort in the table shows a value of +.28 or 128 per cent. Conversely, the minimum combination has a value of -0.39 or 61 per cent. By division, the spread between the best and worst effect the operator can produce is slightly better than 2 to 1. It is important to emphasize that even this spread in productive output can be greatly exceeded by methods changes. It is not uncommon to devise methods by which average operators can triple or quadruple their output at the same performance level.

Evaluating skill, effort, and conditions as separate items makes it possible to apply LMS leveling factors to a one or few cycle study. Although timing of only one or few cycles is not a good time study practice, practical conditions may necessitate the procedure, if the cycle time of the job being observed is very long.

3. SYNTHETIC RATING

3.1 Introduction

Synthetic rating or leveling attempts to provide a rating that is not influenced by human judgment or bias, and at the same time produce consistent results. It is a method of evaluating an operator's speed from predetermined time systems. The procedure is to make a time study in the usual manner, and then compare the actual time for as many elements as possible with predetermined time values for the same elements. This system was developed by Morrow and application of synthetic rating was based on time data developed by Barnes et al [1937]. These tables provide predetermined times only for "grasp" and "place" under different conditions.

3.2 The Application

A ratio can be established between the predetermined time value for the element and the actual time value for that element. This ratio is the performance index or rating factor for the operator insofar as that one element is concerned. The formula for computing the performance rating factor is

$$R = P/A$$

where R = performance rating factor

P = predetermined time for the element, minutes

A = Average actual time value (selected time) for the same element, minutes

The factor thus determined then would be applied to the remainder of the manually controlled elements being studied.

James Gilbert and Walter Bishop used this system to determine the production rate per hour of turning, drilling, threading, facing, recessing, and tapping a brass stem on a turret lathe and established that synthetic leveling provided a more accurate result than judgment rating [Morrow p.448, 1957].

Niebel [Salvendy p. 4.4.15, 1982] gives an example of an analyst making a 15 element study. The analyst may choose three of the short elements - such as "pick up 2 lb casting, place in air chuck, and close" (element 2); "back off crossslide and index turret" (element 7); and "open chuck, remove piece, and place in tray" (element 15)- as those that will serve as the basis for the established leveling factor (Table 3). The mean of the three elemental performance factors would be used as the rating factor to be applied to the entire study:

$$(1.09 + 1.14 + 1.11)/3 = 1.11 \text{ synthetic performance factor}$$

Table 3.

Performance factors for elements

Element Number	Fundamental Motion Data Time (min)	Measured Time (min)	Performance Factor
2	.12	.11	1.09
7	.08	.07	1.14
15	.10	.09	1.11

It is important to note that unweighted averaging of elements gives equal importance to all elements.

Morrow stated that more research was needed in defining and limiting the applications of this leveling system. As the same leveling may not apply for all elements in the study, if one part of an operation is more difficult to perform than the rest, the time standard used for comparison will be greater and would adequately allow for the increased difficulty.

Synthetic leveling is a sampling method and the accuracy and reliability of results are based on statistical procedures. There are limitations to the applications of sampling methods. But these limitations have not restricted the wide application of sampling methods with satisfactory results [Morrow, 1957]

Morrow used this technique to advantage in a factory

which he visited one day a week to check the time studies made by the factory time study men since the last visit. Often the operation to be checked had been finished, short runs were frequent in this shop. By locating the jigs and fixtures which had been used on the operation and visualizing all the motions described in the time study, synthetic times could be constructed for parts of the operation. These parts or elements times then were compared with the original time study element figures and a ratio between synthetic and actual recorded times obtained. This ratio would be the same as the time study rating or leveling, if the latter was correct. However, synthetic leveling should be used only by the highly trained and experienced engineer. Morrow stresses that the important consideration is the possibility of reducing judgment to such an extent that it will no longer play an important part in the final determinations.

4. OBJECTIVE RATING

4.1 Introduction

This rating system was proposed by Mundell [1960] with the view of reducing the amount of judgment entering into time study. Judgment, to be of real significance, should be on some observable or demonstrable basis. The judgment procedure should be such that the judgment is explainable by other means than by mere recourse to "based on experience." The basis must be concrete to permit agreement between labor and management on, at least, the measuring unit involved, or in other words, the concept of normal performance. For any given job, the primary objective phenomenon from which all inferences concerning performance are made is the pace at which the job is being performed. Mundell states that pace is a function of skill, aptitude and exertion of the operator. Operator skill and aptitude can be demonstrated on the basis of the pace of the job alone. Exertion of a given operator is a function of both the difficulty of the job and the pace. Consequently, rating of performance is boiled down to a judgment of not more than two items: (1) observed pace and (2) job difficulty.

4.2 The Application

The Objective Rating procedure consists of the

following two steps:

1. The rating of observed pace against an objective pace-standard, which is the same for all jobs. In this rating, no attention whatsoever is paid to job difficulty and its limiting effect on possible pace; hence, a single pace-standard maybe used instead of a multiplicity of mental concepts.

2. The use of a secondary adjustment, consisting of a percentage increment, added after the application of the numerical appraisal from step 1, to adjust the original observed data. This percentage increment is taken from experimentally determined tables of the effect of various observable factors that control the exertion required at a given pace.

4.2.1 Procedure for performing step 1.

1) The first requirement is establishment of the recommended definition of standard time. Mundell defines standard time for a job as 130 % of the amount of time that will be necessary to accomplish a unit of work, "using a given method and equipment, under given conditions, by a worker possessing sufficient skill to do the job properly, as physically fit for the job, after adjustment to it, as the average person who can be expected to be put on the job, and working at the maximum pace that can be maintained on such a job, day after day,

without harmful effects.

2) Obtaining a physical representation of the above definition of standard time on one very simple task. This could be done in four ways.

a) The analyst can take a simple job involving practically no skills or special aptitudes and determine experimentally the pace on this job when performance meets the requirements of standard time. The experiment may require several operators.

b) The analyst can make a series of films or video tapes of workers working at different paces on a simple job and ask management to select one of these as representing their concept of normal pace. It is worth noting that the pace selected also may be jointly negotiated by labor and management , in which case the accuracy with which it represents the definition of standard is of less consequence, although this will be discovered later through experience with its use.

c) The use of benchmarks such as those established by Presgrave [1945]. Presgrave proposed "Effort Rating" could be used as physical representation of normal pace.

d) A simple job can be shown to large groups

of work analysts and the recorded values averaged can be used as a basis of standard pace.

3) The third step is the formal selection of at least one film or video tape showing the standard rate of activity with any one job. This film should represent the unit of measurement, or the rate of activity representing 100% standard pace. With a record of this type, the standard rate of activity may be actually included in the labor contract. In establishing the standard, it should be noted that experiments have shown that probably about 6 % change in pace is the usual minimum detectable difference [Mundell et al, 1948].

It should again be emphasized that the analyst in performing step one must only judge the pace at which the job is being performed. No attention must be paid to job difficulty and its limiting effect on the possible pace of the task.

4.2.2 Procedure for performing step 2

After step 1 has been performed (for pacing), the analyst is then ready to perform step 2 of the objective rating procedure. All jobs cannot be performed at the standard pace, since practically all will be more or less difficult than the job with which the standard pace was established. Some tasks, will involve heavier assembly

parts or closer visual work. These job differences place different limits on the pace possible on each job with a fixed rate of exertion relative to the maximum possible on the job, and these have been objectively evaluated. The evaluation is completed by determining the various factors that make for difficulty in the job, their effect evaluated, and a "difficulty adjustment" in percentage terms utilized. The factors that affect job pace as indicated by experimental or practical evidence are as follows :

1. Total amount of body involved in the element.

Research has indicated that a 10-inch guided movement takes more time when the movement was far enough away from the body to require a movement of the full arm about the shoulder than when sufficiently close to the body to permit movement primarily about the elbow. Actuation of finger switches using the full arm motion was found to take approximately 8 % longer than when actuation was done using the forearm alone [Mundell et al, 1949].

2. Foot pedals. Studies previously noted indicated that the use of different part of the arm changed the cycle time. Mundell felt that these principles should apply in general to the leg and foot as well. A study indicated that the operation of different foot pedals required different amounts of time ranging, at maximum

pace, from 0.005 to 0.007 minutes [Barnes et al, 1942].

3. **Bimanualness.** The simultaneous use of both hands to perform work on identical parts does not produce a 100 % increase in output. The increment in output for short tasks was found to be approximately 30 % [Mundell et al, 1940]. Ischinger [1950] studied eight industrial workers on five different jobs, to establish the fact that operators performing the one handed version of a task performed 18% faster than using the two handed version.

4. **Eye-hand co-ordination.** Eye-hand co-ordination requirements primarily affect therbligs that are visually aided in performance (such as position and grasp) although other motions accompanying them (such as preceding transports) also are affected [Mundell et al, 1938]. Mundell [Barnes p.74, 1942] has shown that, for a task requiring considerable eye-hand co-ordination, the pattern of eye usage shifts after practice and that a considerable reduction in cycle time takes place

5. **Handling requirements.** Operators, asked to move small cylinders from one place to another as rapidly as possible, took 2 % more time when the initial position of the cylinder was on a surface of needles and 11 % more time when the cylinder was open ended carrying a non-removable ink, than the time taken to move a plain brass

cylinder from one plain surface to another [Mundell et al, 1939].

6. Weight handled or the resistance encountered. Maass [1947] showed that resistance (between 4 pounds and 23 pounds) and pace were linearly related. Solberg's [1946] experiment of asking college students to move a weighted lever up and down as rapidly as possible concluded that the increase in time per movement was essentially linear from 10 to 50 pounds. However it was curvilinear below 10 pounds, decreasing more rapidly at the lower weights. Sekerci [1953] studied the number of times a bar could be lifted during two minute work intervals when the bar was loaded with different weights. He found a linear decrease in the number of lifts per minute as the weight decreased.

The secondary adjustments for the above listed factors are enumerated in Table 4 and Table 5.

Table 4.

Adjustments for job difficulty as used in Objective Rating

Category No.	Description	Reference letter	Condition	% Adjustment
1	Element of member of body used	A	Fingers used loosely	0
		B	Wrist and fingers	1
		C	Elbow wrist & fingers	2
		D	Arms	5
		E	Trunk	8
		E2	Lift with legs from floor	10
2	Foot pedal	F	No pedals or one pedal with fulcrum under floor	0
		G	Pedal or pedals with fulcrum outside foot	5
3	Bimanualness	H	Hands help each other or alternate	0
		H2	Hands simultaneously doing the same work on duplicate parts	18
4	Eye-hand	I	Rough work	0
		J	Moderate vision	2
		K	Constant but not close	4
		L	Watchful, fairly close	7
		M	Within 1/64 inch	10
5	Handling requirements	N	Can be handled roughly	0
		O	Only gross control	1
		P	Must be controlled, but maybe squeezed	2
		Q	Handle carefully	3
		R	fragile	5
6	Weight	Identify by the letter W followed by actual weight or resistance. See Table 6.		

Table 5.

Adjustments due to weight in Objective rating.

Weight, pounds	% adjustment arm lift	% adjustment leg lift
1	2	1
2	5	1
3	6	1
4	10	2
5	13	3
6	15	3
7	17	4
8	19	5
9	20	6
10	22	7
11	24	8
12	25	9
13	27	10
14	28	10
etc.	etc.	etc.

For instance, on an element in a foundry operation, consisting of moving a core plate and core totaling 21 pounds, using both hands and a rotation of the body about the trunk, if the observed time is 0.16 minutes and if rating of 60 % is given for pace, then the secondary

adjustment would be as shown in Table 6.

Table 6.

Secondary adjustments for a foundry operation.

Category	Reference letter	Per Cent
1. Amount of body	E	8
2. Foot pedals	F	0
3. Bimanualness	H	0
4. Eye-hand co-ordination	J	2
5. Handling requirements	P	2
6. Weight	W21	38

Total secondary adjustment 50%

Base time = $0.16 \times 0.60 \times 1.50 = 0.144$ minutes.

Additional allowances will have to be added to the base to make it represent the "allowed time", which is the time required to represent standard time on an all-day basis. Secondary adjustment is not a measure of the rest time to accompany a job, but a measure of the amount of time to be added to the time for the element at standard pace so that the final time will represent the time for the element at the standard rate of exertion. That is the required proportion of maximum physical exertion possible on the job with the standard type of operator. This may or may not be the required proportion

of the amount of time at maximum pace, depending on whether part of the cycle is machine controlled, but this will be taken care of in the allowances.

4.3 Conclusion

Mundel has done extensive work to develop the "Objective Rating" system in order to achieve what he calls a realistic approach for providing a better system of measurement of rating. The claim is that although the ratings may still have errors, the errors will be much reduced by comparison with other systems. In cases requiring considerable precision, average ratings will yield a value approaching a true value rather than a biased value [Gomberg, 1955].

Objective rating is intended to satisfy the following management requirements:

1. A uniform concept of "standard" among the time study analysts.
2. A reduction in rating error.
3. A demonstrable yardstick of "standard."
4. A basis for maintaining a concept of "standard" in subsequent years and with eventual changes in the time study staff.

5. EFFORT RATING

5.1 Introduction

Ralph Presgrave [1945] proposed the "Effort Rating" system. Presgrave explains, 'The term has been selected because of its wide acceptability, and when time study analysts speak of "effort", they have in mind relative production rates.' However, the meaning of "effort" is confined to the concept of speed of movements and carries with it no connotation of the expenditure of energy, or of the effects of skill, even though skill in the broad sense is recognized as contributing to both method and speed of movement. The effort rating system as propounded by Presgrave is more popularly known today as "Speed Rating" or "Performance Rating" and is the most widely used rating system in the world today. Under this method the time study analyst considers only the rate of accomplishment per unit of time. The analyst compares the performance being demonstrated with their own concept of normal performance for the operation being studied.

Under speed rating, 100% represents normal. If an operator were performing at a pace 25% faster than normal, the rating factor would be 1.25. Similarly, if the performance were 75% of normal, the operator would be rated 0.75. To be consistently accurate in using speed

rating, the time study analyst must be familiar with the work being studied. The analyst should have a variety of benchmarks that are used for comparing with the performance being observed.

5.2 The Problem

The problem faced is to discover a method by which any observed degree of speed can be recorded accurately by the time study analyst. No instrument has yet been devised that will do this, and so the matter is left entirely left to human judgment. The question that then arises is, can the determination of any mathematical factor by judgment ever be regarded as measurement in the strict sense? Presgrave says that the answer to this question can be found in the answer to the following questions :

1. Is it possible to give a universal mathematical value to operator speed ?
2. Is it possible to determine this value by mental processes only?
3. If this last is possible, can it apply to all types of manual work?
4. Can it be done consistently over the whole range of speeds?
5. Is everyone capable of rating?
6. Is the method consistent as between different

observers?

7. Is it reliable as between operators?

8. How can it be learned or taught?

The first question can be answered "yes" because of the reasonably close relationship that exists between different activities because of the definable range of effort (range of human capacity).

To answer the second question, it is possible to evaluate operator speed through judgment. Extreme conditions, in which the method is less applicable, by no means invalidates it, for the same is true for all types of measurement. The method is not infallible. However it is applicable to most manufacturing processes and has limits of accuracy that do not conflict with the limits of accuracy of the watch reading, establishment of allowances, and the other major elements in time study.

To answer the third question, the method can apply to all types of manual work, provided the analyst knows what the normal performance is on several of the elements being studied, through the development and orderly cataloging of standard data elements. This information will be a helpful guide to establishing the performance factor of the entire study.

To answer the fourth question, sizable errors in

judgment during rating often are a result of improper evaluation of an operator who is performing at either extremity of the rating scale. For example, if 0.50 minutes is considered normal for dealing a deck of cards into four bridge hands, it will be found that performance within plus or minus 15 % of this conception of normal will be fairly easy to identify. However, once the performance runs 50 % faster or 50 % slower than normal, considerably more difficulty is encountered in establishing an accurate rating factor indicative of performance being demonstrated [Niebel, 1955].

To answer the fifth and sixth questions, inconsistency and inaccuracy results from effort rating when practicing time study engineers have not been exposed to a precise training practice. If training is adequate it is safe to say that that the method is valid as is the stop watch reading, and is so readily attainable that it can be transmitted without deviation from the pattern. There may be individuals who have no sense of "tempo" and so cannot rate well, just as there are some who are color-blind or tone-deaf. Such people usually are rare. Mention of the word "tempo" brings music to mind. In this field the possibility of accurate judgment of speed has been demonstrated time and again. Some artists and conductors have so precise a

sense of tempo that they can produce a lengthy piece of music having internal variations in tempo within specified time limits so close that they represent a much finer tolerance than effort rating needs.

To answer the seventh question, when more than one operator is available to be studied, select the one who is thoroughly experienced on the job, who has a reputation of being receptive to time study, and who consistently performs at a pace near standard or slightly better than standard. The closer the operator performs to a normal pace, the easier will be the judgment task.

5.3 The Training

The answer to whether effort rating can be learned or taught lies in the training method employed (eighth question). The fundamental training in effort rating is a simple process achieved in a matter of hours. Presgrave has established familiar human activities as benchmarks for this system. These are:

1. Walking at 3 miles per hour, taking 27-inch steps, on level ground and carrying no load. Presgrave makes a reference to the experiments conducted by Haldane [Vernon p.48-50, 1921] relating oxygen consumption to the expenditure of physical energy in walking wherein it was revealed that a man consumes less oxygen per mile until

he reaches approximately 4 miles per hour. Here the law of diminishing returns sets in and at speeds above 4 miles per hour the consumption per mile is greatly increased. Despite this Presgrave established a standard of 3 miles per hour which he admitted was arbitrary but which he claimed reasonable. Subsequent experimentation has shown that Presgrave's assumption is right [Van der Walt et al, 1973]

2. Presgrave arbitrarily applies a factor of 47 % to the walking standard, based on the assumption that the running record for any distance greater than the mile is 45 to 50 % faster than the walking record (which is questionable), to get a running standard of 4.4 miles per hour.

3. Typing at 50 words per minute. (Presgrave does not specify the type of typewriter.)

4. Dealing a pack of 52 cards into 4 piles in 0.50 minutes.

There are those who do not believe that rating can be taught by observing walking, that there is no carry-over to other dissimilar activities. This is not entirely the case, but it is true that the ability to rate is strengthened by studying other operations. The main use of the walking method is to make clear the whole

general idea of speed within a range, and of the essential difference between speed and the method , or between effort and skill, even though in terms of the final results they are indistinguishable.

A further objection to using walking as a training method is that variations in length of pace, arm-swing, etc., tend to confuse the would-be rater and prevent him from cross-checking his ratings as closely as seems desirable. Consequently it is well to supplement this basic rating by experimentation with some activity that is not so subject to method variation.

It has been suggested in some cases that movies or video tapes be made of different jobs at different speeds to train large groups. Loops could be used at varying speeds so that ratings could be checked more precisely. This, too, is a valuable adjunct to training but it has its limitations and can only be used with complete satisfaction on those operations in which speed changes do not of themselves force changes in method upon the normal operator.

5.4 Limitations of Effort Rating

The limitations are three:

1. The difficulty of rating above or below a

certain range of speed.

2. The difficulty of rating certain types of operations.

3. The problems of method.

The last is not a true limitation on the actual effort-rating procedure, but, because it may nullify the results of the most accurate rating, it is included.

The question of rating extreme degrees of speed usually presents no serious obstacles to accurate work, but it must be recognized that it is difficult to rate speeds outside the range of 20 % below standard to 60 % above standard. There seems to be an almost universal tendency, even among expert raters, to be slightly low in estimating high speeds and slightly high in estimating low speeds. The slow speeds would not be difficult to rate were it not that the observer sees them so rarely that the analyst is not sure when they are encountered. The high speeds are difficult and sometimes impossible to rate with confidence because the motion of the hands at speeds higher than about 50 % above standard are more rapid than the eye can follow in most operations. With the knowledge of these difficulties in the back of the analyst's mind, the analyst is reluctant to rate as high or as low as should be done, for fear of setting unduly loose or unduly tight standards.

The second obstacle to accurate effort rating, that the job that does not lend itself to rating, is a little more serious than the foregoing, for instead of confining the problem to certain operators, it extends it to certain operations, thus encompassing all operators performing them. The problem areas are heavy jobs, "high skill" jobs, inspection jobs and "manual pressure" jobs.

Presgrave states that such operations will become rarer as "de-skilling" develops (mechanization increases). These operations are readily recognized when it is remembered that effort rating can deal only with actual motion. Among such operations are extremely heavy jobs in which speed of motion is almost entirely subordinate for gross physical effort. The real problem in energy-consuming jobs is that of fatigue, and there may be a tendency to confuse the rating by inadvertently including therein an allowance for fatigue. Speed rating is one thing and the fatigue resulting from maintaining a rate of speed is another. They should be handled differently and should not be combined except in terms of the final standard.

More difficult to rate than heavy jobs are those more delicate operations in which motions are too minute to assess, in which precise locating is essential, in which there is an element of inspection and judgment, or

in which some special kiesthetic sense is a major factor. In delicate as well as heavy jobs, it is also frequently the case that certain elements will be of a more commonplace type and that the rating on these can be projected over the study as a whole. However, this extension of rating has an element of risk in it, for there is no guarantee that any operator will perform all elements at similar rates of speed.

Another type of operation that is a thorn in the flesh of both time study analysts and plant executives is that of which inspections forms a part. The problems are matters of deciding on the degree of inspection, on the frequency of inspection, and on what the inspector is inspecting for.

There is one other type of element which may be extremely difficult to handle both in rating and in the appraisal of method. These operations involve manual pressure, for example, polishing, grinding, burring, etc. It is very easy for the operator "to take the analyst for a ride" by not applying the optimum pressure combined with the fewest possible strokes. In such cases the method of using the ratings obtained on other elements as a basis for rating the doubtful elements is of little value.

The third problem of effort rating is created by variations in the motion pattern. As a rater it is easy for the analyst to say that the speed of the operator is so and so, doing the job the way the operator is doing it. But, as a person charged with the responsibility of correctly evaluating an operation, the analyst has no formula by which the way the job is being done can be corrected. This problem is not a matter of measurement but of analysis-- a problem of micromotion study, of close observation, of careful selection of element times, of experimentation in cooperation with workers and supervisors.

5.5 Conclusion

Barnes [1945] has performed some interesting work in an effort to determine to what extent a rater can be trained to estimate pure speed accurately. Although his results show that there was some improvement in the ability of time study analysts to rate walking accurately, he warns: "No claim is made that the result of a walking experiment is a true index of the overall ability of a man to set standards."

The practice followed by time study analysts when speed rating is to make two judgments. The analyst first appraises the performance in order to determine whether

it is above or below the analyst's concept of normal. The analyst then determines in what precise position on the rating scale the performance should be placed.

6. PHYSIOLOGICAL RATING

6.1 Introduction

Over the years many people have sought an objective method of measuring physical work. Fredrick W. Taylor saw the great need for work measurement and created stop-watch time study to perform this function. In developing the time study technique, he experimented with the concept of horsepower (that is, foot-pounds of work per minute) as a measure of work but found this approach to be unsatisfactory.

Around the turn of the century, physiologists demonstrated the validity of using rate of oxygen consumption as the basis for measuring energy expenditure. Later studies showed that the change in heart rate also was a reliable measure of physical activity. Extensive human energy expenditure studies have been carried on in various parts of the world. Studies have been made to gain new knowledge about human performance, to better understand the behavior of champion athletes and to aid the physically handicapped.

Interest in work physiology has increased partly because a more objective method of measuring physical work was needed and also because better equipment has become available for measuring oxygen consumption, heart

rate and ventilation rate.

Physical work results in changes in oxygen consumption, heartrate, pulmonary ventilation, body temperature, and lactic acid concentration in the blood. Although some of these factors are only slightly affected by muscular activity, there is a linear correlation between heartrate, oxygen consumption, and total ventilation, and the physical work performed by an individual. Of these three, heart rate and oxygen consumption are the most widely used for measuring the physiological cost of human work.

6.2 Methods

6.2.1 Heart Rate Measurement The heart rate of an individual at rest starts to increase just before the person starts to work and levels off during the work period. When working is stopped, heart rate drops and finally returns to the original resting level. The increase in heart rate during work may be used as an index of the physiological cost of the job. The rate of recovery immediately after work stops also can be used in some cases in evaluating physiological cost. The total physiological cost of a task consists not only of the energy expenditure during work but also the energy expenditure above the resting rate during the recovery

period, that is, until recovery is complete.

Each time the heart beats a small electric potential is generated. By placing electrodes on either side of the heart, this potential can be picked up and transmitted by wire or by radio transmitter to a receiver. There the individual heartbeats can be counted directly, or by means of a cardiometer the impulses can be converted into heart rate, that is, heart beats per minute. These data can be recorded continuously on ruled graph paper by a recorder.

Information concerning rate of recovery also can be obtained simply by using a stethoscope and stop watch. Studies made at the Harvard Fatigue Laboratory showed that heart rate data obtained in this manner are reliable and easy to secure. The procedure consists of obtaining the total number of heart beats during the second half-minute after work stops. Then the number of heart beats is taken during the second half-minute of the second minute, and the second half-minute of the third minute. Such data make it possible to compare the rate of recovery during different working conditions.

A compact, lightweight, two lead heart rate recorder which records signals up to 26 hours can be worn by the worker. An event marker button, when depressed by the

worker, records an event mark on the tape for precise time/event correlation.

An automatic tape scanning system, called Electrocardioscanner, permits the recordings to be played back at real time recorded speed, or at rapid speeds of 30, 60, or 120 times real time. All tape scanning, summarization, and real time documentation is automatic. Heart rate is shown as a trend on an oscilloscope and is printed automatically on a summary trend chart. Heart rate is recorded over a range of 0 to 250 beats per minute.

Davis and Luders [1963] examined the suitability of heart rate as a means of measuring human performance and sought to (1) determine the relationship between the increase in heart rate from a resting to a working level and the speed of performing selected tasks and (2) appraise some conventional work measurement methods on the basis of physiological loads imposed by selected tasks.

The three tasks were:

- (1) Filling a standard pegboard (using the two-hand method for which an accepted benchmark is 0.41 minutes).

- (2) Pump, (a standing subject moved down the

horizontal handle of a closed circuit hydraulic pump through 11 inches up and down strokes requiring a 5 lb force for operation). The normal cycle time was established at 0.015 minutes

(3) Moving cartons (13 in. x 10 in. x 11 in. containing 39 lb of sand) a horizontal distance of 36 inches. The normal time for moving one carton was 0.0415 minutes.

The three work paces at which each task was performed were 70 %, 110 % and 150 % of the normal speed. A Litton BioPack, carried in the subject's pocket, was used to record the heart beat.

Some very useful conclusions drawn were :

1. For the three tasks, heart rate above resting level increased linearly with the speed of task performance.

2. For tasks 1 and 2 (light physiological loads), the physiological responses, in the form of increased heart rate above resting level, were very small compared to large changes in the speeds of task performance. For task 3 (moderately heavy physiological load), there were significant changes in heart rate corresponding to large changes in speed of performance and output, limiting the usefulness of heart rate to conditions of medium to heavy

muscular effort.

3. For each task, the physiological loads on the subjects , as measured by increased heart rate above resting level, are not equivalent for the different work paces; in classical systems these are considered equivalent. This proves that classical or predetermined work measurement systems based as they are on subjective evaluation of the speed of task performance are unrelated to the physiological costs of work.

6.2.2 Oxygen Consumption Measurement Change in the rate of oxygen consumption from the resting level to the working level is also a measure of the physiological cost of the work done. In order to measure the oxygen consumed per unit of time, it is necessary to measure the volume of air exhaled and the oxygen content of this air. Oxygen consumption may be defined as the volume of oxygen (expressed in liters per minute) which the individual extracts from the air inhaled.

A common method of obtaining this information is by means of a portable respirometer. This is a light weight (5 lb) gas meter which can be worn on the back. The person is equipped with a mask and a 1-inch rubber tube which carries the exhaled air from the mask to the respirometer. The respirometer indicates directly the volume of exhaled air in liters . A sample of the

exhaled air is drawn off at random intervals into a rubber bladder, and an analysis of its content is made. This permits a comparison of the oxygen content of the sample of expired air with that of the air in the room.

6.2.3 Physiological acceptable standards According to the American Heart Association [1972], the maximal aerobic capacity (the highest oxygen uptake the individual can attain during physical work breathing air at sea level) for men of 30 to 39 years of age is 8 to 10.5 kcal/min, 11 to 13.3 kcal/min, and 13.6 to 16.8 kcal/min for men in a fair, average and good cardiorespiratory fitness classification, respectively. The numbers for low and high classifications are slightly lower and higher. Kamon and Ramanathan [1974] reported that the average maximum aerobic power for the 35 year old and older male workers is less than 15 kcal/min. Chaffin [1972] estimated that probably 80 % or more of American men have an aerobic capacity below 16 kcal/min. U.S Department of Health and Human Services [1981] recommends an aerobic capacity of 15 kcal/min for men and 10.5 kcal/min for women. It also is stated that these limits maybe too high for a deconditioned aging work force.

A lot of research has been conducted for determining the acceptable energy expenditures for an 8-hour workday. Though a controvesy exists over an appropriate value, it

is generally believed that 33% of the maximum aerobic power of a normal healthy person or 5 kcal/min is the maximum energy expenditure that should be expended for an 8-hour workday [Garg, 1986]. Ekblom et al. [1968] reported increased levels of blood lactate for legwork at levels above 5 kcal/min in well-trained individuals. Rodgers [1978] also supported a 33 % of maximum aerobic power in concluding " We have observed that most people will select a level of effort that keeps them within 33 % of the maximum capacity guideline and will also integrate other factors such as : biomechanical aspects, environmental characteristics, individual fitness and skill level, etc..."

6.2.4 Ventilation rate measurement Most research involving the application of metabolic methods for the physiological evaluation of performance rating has been directed toward the use of cardiac conditions and oxygen consumption. In these measurements, an individual's ventilation rate was obtained more or less as a byproduct of the main objective, determining oxygen consumption. It is a matter of recording the total volume of pulmonary air expired and dividing this by the number of minutes during the timed period. Karpovich and Rankin [1946] found that there is less variation in the relationship between lung ventilation and body surface area at rest

than during work. The attempt of Ayoub and Manuel [1960] to determine whether ventilation rate could be used as a physiological method of rating the performance of workers on repetitive sedentary type of work deserves discussion.

Ayoub and Manuel obtained ventilation rates. Pulmonary air is completely saturated with water vapor and exists at body temperature and atmospheric pressure. When the air is expired into the gasometer, the air temperature drops to ambient room temperature and the water vapor volume is reduced. When the volume of expired pulmonary air is converted to conditions of standard temperature and pressure and all water vapor is removed, it is expressed as a dry volume of gas at zero degrees and 760 mm of mercury.

Filling a pinboard as proposed by Barnes [1980] and dealing a pack of cards as proposed by Presgrave were chosen to be performed by 18 male and 18 female subjects. Each task was performed at 80 %, 100 and 110 % of the standard pace and the pulmonary ventilation rates were recorded.

Conclusions drawn for using ventilation rate as a measurement were :

1. Ventilation rate is linearly related to pace, provided job difficulty remains constant, for repetitive

type of sedentary work.

2. There was a significant difference between the ventilation rate / Body Surface Area (BSA) for males and females, requiring two separate performance scales, one for males and one for females.

3. There was a significant difference in the ventilation rate / BSA between the two tasks. The ventilation rate / BSA for filling the pinboards required a greater ventilation rate than the cards for all three paces, pointing to a physiological difference in the two benchmarks used to represent standard performance.

6.3 Establishing Time Standards By Physiological Methods

Time standards established by time study, standard data or by predetermined time systems are generally set so that the average qualified, well-trained, and experienced operator working on a manual task against the time standard can produce at a level of approximately 125 % day-in and day-out when employed in a plant where wage incentives are used. It is expected that approximately 96 % of the working population can meet or exceed the standard. It is known that some people can attain the 100 % performance level much more easily than others. As a result, some people regularly work at a level of 150 to 160 %, whereas others using the same expenditure of

energy may attain a level of only 110 or 115 %. Time standards are set for the task, that is, for a specific and carefully defined job. Physiological measurements can be used to compare the energy cost on a job for which there is a satisfactory time standard, with a similar operation for which there is no standard, but the comparison should be made for the same person.

Brouha [1960] has compiled a classification of work loads in terms of physiological reactions as shown in Table 7.

Table 7.

Classification of Work Loads in Terms of Physiological Reactions

Work Load	Oxygen Consumption (liters / min)	Energy expenditure (calories / min)	Heart rate (beats / min)
Light	0.5 - 1.0	2.5 - 5.0	60 - 100
Moderate	1.0 - 1.5	5.0 - 7.5	100 - 125
Heavy	1.5 - 2.0	7.5 - 10.0	125 - 150
Very heavy	2.0 - 2.5	10.0 - 12.5	150 - 175

6.4 Conclusion

To summarize, oxygen consumption and heart rate can be used for rating medium to heavy work. Further, as oxygen consumption does not change appreciably with a

change in temperature, the heart rate criteria should not be used for measuring in hot environments. For sedentary work, ventilation rate can be used as a suitable rating system.

7. OTHER RATING SYSTEMS

7.1 Introduction

In addition to the rating systems discussed so far, there exist a few rating systems which have not found widespread use. These are Skill and Effort rating, pace rating, Hummel rating system and the Shumard Rating system.

7.2 Skill and Effort Rating

Around 1916 Charles E. Bedaux [Barnes p.288, 1980] introduced the Bedaux system of wage payment and labor control in the U.S.A. His plan was based on time study, and his time standards were expressed in points or "Bs". The Bedaux unit of human power measurement, called the B, was simply another name for what we now call a standard minute. His time study procedure included the rating of the operator's skill and effort and the use of a standard table of fatigue allowances. Bedaux used 60 points equal to standard performance. Thus, an operator working at a normal pace was expected to produce 60 Bs per hour. It was expected that the average incentive pace would be around 75 to 85 points per hour.

Before Bedaux, performance rating had been done mainly by selecting stop-watch readings from the time

study data. Thus, if the operator was judged to be working at a fast tempo, a watch reading considerably above average would be selected as the representative time for the element; if the operator was judged to be working at a slow tempo, then a watch reading below average would be selected. The Bedaux system was a definite improvement over this informal method of rating operator performance.

7.3 Pace rating

The term is employed in some companies, notably U.S. Steel Corporation, to describe the system of performance in use. While the technique incorporates most of the ideas of effort rating, two other devices are used to assist the person doing the rating and to extend the scope of the application. Thus, it is recognized that all jobs are not performed at the same tempo, so that the pace or speed observed must be related to a concept of normal for the type of work involved. The time study analyst uses a number of concepts of normal, depending on the type of work being observed. Where his work is limited to one type or a few, the standards or normals would be correspondingly limited.

In order to assist the analyst in the acquisition of a set of concepts that is uniform for all analysts, a series of bench marks have been provided in different

types of work. These have been quantified in specific rates of production. Thus, walking on a smooth surface, without load, at X miles per hour is one standard. This and other standards can be duplicated or viewed on film and thereby provide an objective interpretation of the pace described. Rating is expressed as a performance percentage above, below, or at normal, and the ratio or factor is applied to the selected time for the element. An attempt is made to minimize the effects of other variables by studying those operators who are judged to be adequately qualified and trained to do the job in question.

7.4 Hummel rating system

The Hummel rating system is a performance rating technique developed by J.O.P. Hummel, Professor of Industrial Engineering, The John Hopkins University. This method relies on two criteria in the determination of performance level. Here the term "tempo" has been assigned as a synonym for effort, and the word "effectiveness" as a term somewhat comparable to skill.

These terms are defined as follows: (1) "tempo" is the relative rate of performing, or the speed of doing work; (2) "effectiveness" is the degree of co-ordination or the lack of false, unnecessary or non-productive

movements.

Tempo ratings are made in terms of percentage: 100 % is considered normal. Tempo ratings cover a range from 60 % to 130 % in increments of 5 %.

Effectiveness is rated as either superior, excellent, good, average, fair, or poor; the values of each of these categories are as shown in Table 8.

Table 8.

Effectiveness ratings

Category	Value
Superior	+0.15
Excellent	+0.10
Good	+0.05
Average	0.00
Fair	-0.10
Poor	-0.20

These characteristics are described as follows:

Superior - Operator works with very nearly perfect smoothness of movement and co-ordination making full use of hands, arms and body.

Excellent - Operator works with a high degree of smoothness of movement and coordination.

Good - Operator works reasonably smoothly, unbalanced movements and hesitations are present occasionally but are not readily deleted.

Average - Operator does not noticeably have excess or unbalanced movements or hesitations.

Fair - These are occasional unbalanced movements indicating unsatisfactory co-ordination. Occasional hesitations.

Poor - Movements of hands, feet, or body are poorly co-ordinated. There are frequent hesitations.

In determining the performance factor using the tempo and effectiveness method, the analyst multiplies the tempo assigned value by the effectiveness algebraically added to unity. For example, if a tempo value of 1.10 be assigned and an effectiveness rating of "good" is given, then the performance will be:

$$P = (1.10) (1.05) = 1.155$$

Thus, in this case, the operator would be performing 15.5 % faster than the time study analyst's concept of normal. This leveling technique has a spread of .48 to 1.495, or is based on a range of productivity of 1.3 to 3.12 [Niebel, 1955].

7.5 Shumard rating system

Shumard [1940] developed a performance rating

method which is claimed to be used successfully in many plants. The speed of the operator only is rated in speeds from 40 to 100 (Table 9).

Thus the leveling multiplier to convert the performance time of a "good plus" operator to that for a "normal " (60 rating) operator would be $75 / 60 = 1.25$. The normal time thus obtained would be 25 % greater than the actual time taken by the "good plus" operator.

Shumard selected 60 as the normal, corresponding with the speed shown by the normal worker under standardized conditions, who is working at a brisk rate but without any financial or other incentive except that attending the hourly basis common to the average factory. He designates 80 as an excellent speed and one that the operator on an incentive basis would usually attain.

Table 9.

Speed ratings by Shumard

Rating	Speeds	Rating	Speeds
100	Superfast	55	Fair Plus
95	Fast Plus	50	Fair
90	Fast	45	Fair minus
85	Fast minus	40	Poor
80	Excellent		
75	Good plus		
70	Good		
65	Good minus		
60	Normal		

8. ASSESSMENT OF RATING SYSTEMS

8.1 Introduction

Few topics in the field of Industrial Engineering have provoked as much destructive criticism, emotional defense, or genuine frustration as has human work measurement. On the one hand, it does not seem to matter to the "faithful" that critics have identified serious flaws in the scientific foundations of traditional work measurement methods; on the other hand, it does not seem to bother the modern cult of critics that their attacks are largely of a destructive nature, offering few if any constructive alternatives, or that commonly proposed "solutions" are oblivious to the fact that it is work content not labor time which the Industrial Engineer must measure [Smalley, 1967]. The rating process, if it is to be meaningful in even an empirical sense, depends upon a completely operational definition of the concept of validity and precision. Validity is the term associated with the legitimacy of the level of work itself, defined as the standard. Precision defines the limits within which the standard is reproducible at a specific probability level.

Gomberg [1955] finds it interesting to analyze existing rating methods and the rationale underlying them

with the concepts of validity and precision clearly in mind. The professional engineering societies have recognized that the rating concept must be standardized if the occupation of the time study analyst is to secure professional recognition. The Society for the Advancement Of Management set up a rating committee to study the problem. Gomberg claims that confusion exists on what the committee was to search for and what the committee finally did. The definition of the rating process laid down by the National Committee on Rating [1952] discloses its completely subjective character. They say: " Rating is the process during which an observer evaluates the performance of the operator in terms of the observer's own mental conceptions of the proper or normal performance of that job".

8.2 Leveling and Rating Methods Compared

If normality is defined as the arithmetic mean of the parent population which is accepted as exhibiting the distribution of acceptable production rates, it becomes somewhat difficult to determine the merits of the conflict between the LMS system and Presgrave's effort rating. This conflict takes place on two levels: (a) the factors which go into the rating process and (b) the allowable range within which the variation of productivity falls. Gomberg claims that the first is

largely academic while the second is exceedingly important inasmuch as it determines the population of acceptable workers in a factory.

Presgrave used Wechsler's [1952] estimate of the range of human motor capacities of 1:2.23. An examination of the origin of the table from which this figure was computed indicates that it was made up of capacities such as flexion of wrists, tapping, simple reaction times etc. Thus, the perceptual function of the work at hand has been completely eliminated. Presgrave was within his rights in using this range since he restricted this range to speed of movement only. However, his attempt to restrict rating to measuring the speed of movement only is open to question. The range which he finally accepted was 1:2.25

Lowry, Maynard, and Stegemerten [1940], on the other hand, indicated a range of productivity of 2.76:1, that is, from 50 % to 138 per cent. Although the normal should be defined as the midpoint of the range, the three investigators have protected themselves by recommending the discharge of those with skills below average. As the result of a process of selection, the normal would no doubt fall in the upper part of the actual distribution, specifically at 2.00, instead of at the midpoint.

The three investigators do not indicate how the their allocations to skill, effort, consistency and conditions (Table 2) were derived. They claim that they were worked up from comparison studies of about 175 men over a period of years before 1927. Without the original figures, the origin of these allocations cannot be investigated. Gomberg feels that the allocations do not seem to possess too strong a rational base.

Presgrave [1945] attacks this method of leveling because skill is listed as a leveling element. Presgrave objects that skill is a matter of method, to be taken care of by motion analysis. He states " Motion analysis and correction are not matters of leveling factors or of rating, but must be achieved by selection, by elimination and by adjustment. To rate for skill, to attempt to measure it and express it by a number, is a fault that all time study men fall into in some degree".

Presgrave was quite right when he pointed out that it was difficult to reduce skill to a number. But will motion analysis solve the problem of relating skills by standardizing motion patterns ? Psychologists feel that this is highly doubtful. In support of selection, Sakuma [1975] has established that therbligs requiring intermediate control correctly reflected the work tempos. However therbligs requiring easy control overly reflect the

work tempo and therbligs requiring difficult control do under reflect the work tempo. Gomberg feels that elimination might be acceptable if job opportunities were abundant. Until they are , he feels that it is unacceptable as a remedy. Gomberg goes on to add that adjustment is but another word for what Lowry, Maynard, and Stegemerten were attempting to do, however inadequately. Thus Presgrave may have been right in asserting that the three investigators have not treated skill correctly, but if he was right, it is for the wrong reason.

Presgrave is quite correct when he argued that one operator performs at a higher rate of productivity than another for one or both of two reasons:

1. He performs identical motions with greater rapidity.
2. He performs the operation in a different manner.

But taking the latter problem out of the field of time study merely transfers it to another field where its basic insolubility will still plague time study techniques.

Gomberg feels that relative skill must be accounted for in time study practice. Smalley [1967] feels that making allocations for skill (Westinghouse System) is

not valid, as this goes against one of his postulates of work measurement theory, that is, "The human work content of a specifically defined human task is a constant which is equivalent to the physiological and psychological energy required in performing the task according to the prescribed method." Thus, Smalley implies that only one level of skill is tolerable- that which corresponds to the perfect adherence of the standard method. Superfluous motions (or elements) are "removed" and omitted motions (or elements) are "restored" by mentally either reducing or increasing the effort rating which would have applied had no deviation in the method occurred.

In a sense both of these variations are based upon Bedaux's philosophy of setting a normal time for the "best" method and expecting the worker to find this method in order to attain standard performance at a normal effort level. Smalley attacks the provision for consistency stating that attributing high variability in the observed time distribution to subnormal effort assumes that perfect consistency corresponds to normal effort, implying that average effort is equal to normal effort which he feels is totally unrealistic in view of motivational requirements of the incentive effort level. Smalley attacks provision for "conditions" stating that this provision is better handled separately in applying

allowances for fatigue and personal needs. Gomberg also attacks the provision for "conditions" stating that it is unwise to place a ceiling on allowances for conditions . If conditions are bad, they should be corrected. Having an allocation of 20 % for extremely bad conditions is unwarranted. Smalley states that only "effort" of the four Westinghouse factors is consistent with the requirements of work measurement theory.

H.B Maynard [Gomberg p.184, 1955] agreed that his leveling method fails to account for subtle differences in motion patterns used.

In reviewing Presgrave's concept of effort rating , the principal objection to the procedure is that it seems to place a premium upon just plain speedup. Presgrave has also admitted that effort rating fails when wide differences in productivity are traceable to minute differences in motion patterns used by different workers. The only sound basis upon which effort rating becomes a useful concept is the assumption that all people can be trained to use identical motion pattern down to the last muscular reaction. Gomberg feels that even though it is difficult to assess the distinctive value of the effort rating technique, factors other than the speed must be considered. Holmes [1938] is dissatisfied with the Westinghouse system and rejects it in favor of pure speed

rating. He states that " with a speed standard and a knowledge of what can and should be done, and what motions are necessary and unnecessary, considerations of skill and consistency are a useless expenditure of time."

Kannon [1969] has determined that for experiments involving one dimensional stimuli and two dimensional stimuli, that the amount of information that can be absorbed is 2.6 bits (on an average) and 4.6 bits (on an average) respectively. He thereby concludes that as more variables are added to the input, the total capacity increases but the accuracy for any particular variable decreases. Thus people are less accurate when they must judge more than one attribute simultaneously. From this result he concludes that effort rating is far superior to any other method since the analyst deals with only one variable- speed. Martin [1970] observes that the two concepts of method and motion speed are fundamentally different. Concentration on speed is sound only if it is the responsibility of the analyst to train the operator in methods at the 100 % level and see that the operator achieves such a level during the study interval.

8.3 Objective Rating

Kannon states that none of the existing rating systems can handle "variations in the method" adequately. He is of the view that the next best thing is Mundel's Objective rating method wherein both speed and difficulty of the job are treated as one dimensional stimuli.

Objective rating sets no limits on the possible variation within the working force. The first part of Objective rating is simply speed rating while the second part of compensating for the job difficulty resembles the technique of job evaluation. It is a method whereby the analyst projects himself into the position of the worker and asks : How much ought I add for the relative difficulty of maintaining this job at this pace. Mundel himself confesses that the presently available data for secondary adjustments leaves much to be desired. Lifson [1953] has done some pertinent work in analyzing the effectiveness of this method of rating. The purpose of his study was 1) to compare the worker's judgments with the time study analyst's pace ratings. 2) To determine the effects upon the pace ratings which may result from actual performance of the jobs by the time study analysts. Lifson's conclusions were: (1) workers judgments on equating the jobs differ from the pace ratings, (2) some workers can judge more reliably than

time study analysts can rate, (3) doing the job changes the time study analyst's pace ratings. The concepts of normal on jobs changed.

Lifson's conclusions tend to support the rationale behind Objective rating as the most useful of the empirical techniques yet available, provided we do not restrict ourselves to Mundel's correction factors. First hand familiarity with the job influences the mental concept of normal envisaged by the time study analyst.

Martin [1970] points out that in Objective rating the errors can be two fold. It not only includes the errors of speed rating but also errors due to variations in job difficulty. Gambrell [1959] questions the validity of the assumption that time study analysts can rate pace and that they are not influenced by job difficulty during the rating process. His experiment of rater's having to rate a task involving movement of boxes established that both weight and size of the boxes had a significant influence on pace ratings. Gambrell rejects the hypothesis that skilled , thoroughly trained , and practicing time study analysts using pace rating are not influenced by job difficulty.

8.4 Synthetic rating

The usefulness of this method depends upon two

assumptions: (1) The fundamental standard times for these known elements are valid . (2) There is a uniform relationship in the speed of the different elements to the speed of the overall cycle. This latter assumption has been proven false by Schwab [1948]. Random comparisons with predetermined times is questioned by Martin [1970]. He feels that this makes a major assumption that the ratio of synthetic time increments to the observed time increments indicates a performance rating that is applicable to other elements as well. Research has indicated that it is not valid to rate only one or even a few of the elements of a work cycle for the purpose of obtaining a rating factor for the entire study, if the resulting standard is to be within plus or minus 5 % of the average standard. This is because the trend in the variability between the different elements of a particular operation for a given operator is different from other operators doing the same operation [Jinich, 1970].

Niebel [Salvendy p. 4.4.16] makes another objection to this rating method is the time required to make a right- and left-hand chart and to assign and summarize the fundamental motion times. One might suggest that it would be more expeditious to compute the normal time for the entire time study with one of the fundamental motion

data systems. This certainly would be appropriate when the cycle time is relatively short for example, less than one minute. However, considerable time would be saved using the Synthetic performance rating system when the cycle time of the elements are 5 minutes or longer.

8.5 Physiological rating

Moore [1970] reported energy expenditures of 6 to 12 kcal/min for four different jobs performed at the same standard performance rate as determined by stopwatch time study. Thus, the expected performance for an operation differed as to whether it was expected by the work physiologists or time study engineer. The primary variables responsible for these differences were rating of the job and fatigue allowances [Garg, 1986]. Moore [1970] demonstrated that as the work rate increased the energy expenditure increased at an increasing rate, whereas the performance rating assessment increased, but at a decreasing rate. Garg et al. [1986] found no significant correlation between energy expenditure and performance index and heart rate and performance index in physically demanding tasks.

Garg [1986] is of the view that established benchmarks were developed in the manufacturing sector for determining time standards for bench or assembly type of

operations i.e., for jobs which were highly repetitive and more sedentary in nature and not for physically demanding jobs, such as warehouse operations. Garg recommends the integration of physiological techniques with conventional practice, as he feels that working at recommended work loads based on traditional work measurement techniques will result in increased incidences of injury and illness. However, it should be pointed out that the use of some of the physiological methods of rating requires the operator to wear equipment which might hinder his ability to work at a particular pace.

8.6 Shumard Rating System

Gomberg feels that the Shumard rating system follows along the same lines of effort rating as Presgrave's effort rating. Mundel [1960] has ridiculed this system, quote, "...the use of loose arithmetic leading to the introduction of additional decimals makes the method look much more exact. Such procedures would be amusing if they were not in use."

8.7 Conclusion

From a practical standpoint, only Speed rating and Objective rating are applicable if one wishes to performance rate each element of the cycle. All the

techniques can be readily used where performance rating of each cycle or periodic rating takes place. Certainly the majority of time studies of 30 minutes or less are taken by applying only one performance factor to all effort elements of the study. (Machine -controlled elements are always rated 1.00.)

In general, the performance rating plan that is easiest to explain, understand, and apply is speed rating when augmented by standard data benchmarks. The standard data bench marks may be determined from previous standards developed from the stopwatch procedure or from fundamental motion data.

9. PREDETERMINED MOTION TIME SYSTEMS

9.1 Introduction

When using Predetermined Motion Time Systems (PMTS), performance rating is no longer necessary, since the data of PMTS currently in use were leveled to a common base at the time of development. Work Factor and MTM, the most popular generic PMTS in use today and will be taken up for further discussion. Other PMTS include Motion Time Analysis [Segur, 1964] and Basic Motion Time study [Presgrave et al, 1963]. Note that a basic-level system is one whose elements consist mostly of single motions that cannot be further subdivided. A second level system is developed by combining two or more of the single elements of a basic - level system into a multimotion element. Third and fourth level systems also can be generated by continuing the combining process. A "generic" system is one that is intended to be understood by all users of work measurement and that is not restricted in application. A "functional" system is one that is adapted to a particular type of activity. A "specific" system is proprietary in nature and is adapted for a particular industry or organization.

9.2 The Work Factor System

Industrial engineers Benner, Quick, Shea and Koehler

initiated research on Work-Factor. Their research objective was two fold : (1) To minimize engineering judgment in establishing performance standards, by accurate description of the work cycle in terms of the individual work motions required and by the use of accurate standard time values for these individual work motions. (2) To develop a practical rate-setting technique embodying time values applicable to highly repetitive work cycles (mass production) and applicable to non repetitive work cycles such as those encountered in job lots and maintenance. The techniques were to be readily understandable by the worker, the engineer, and the management. The general approach throughout the research was one of accumulating large masses of data. This was accomplished by a team of 25 engineers in machine shops, assembly plants, wood mills, maintenance shops and other specialty shops in the Philadelphia area. Production quantities ranged from extremely short orders to mass-production quantities. Motion times established for use in the Work-Factor System represent times required by an average of experienced workers as leveled to an incentive pace by an average of experienced engineers. Final data was resolved into curves, and formulas were derived for various body members [Quick et al, 1962].

9.2.1 Detailed Work Factor System This generic, basic level system was developed from original motion time studies using stopwatches, photo timers, and fast-film snapshots. The detailed time unit is .0001 min (Table 10). Rating was based on the evaluation of skill and effort of operators while being studied.

Table 10.

Range of Detailed Work-Factor times

Elements	Time Ranges (Minutes)
Transport (reach and move)	.0016 to .0236
Grasp (Gr)	0 to .0189
Preposition (PP)	0 to .0120
Assemble (Asy)	.0018 to .0130
Use (Use)	(Varies with process)
Disassemble (Day)	0 to .0088
Release (R1)	0 to .0088
Mental process (MP)	.0020 to .0030

9.2.2 Mento-Factor System This is a basic-level system that was developed to determine the time required for measuring mental processes such as those involved in decision making.

9.2.3 Ready Work-Factor System This generic, second-

level system was developed by simplifying Detailed Work-Factor time values. The Ready Work-Factor time unit is 0.001 min.

The system is particularly suitable for measuring medium to long-run operations with cycles of 0.15 min and greater. It can be taught to supervisors and employees relatively quickly.

9.2.4 Brief Work-Factor System This generic, third level system was developed for measuring non repetitive work. The Work-Factor foundation lists these features:

1. It uses time values applied to segments of work rather than individual work motions.
2. There are six time values and 27 classifications.
3. This system uses only four time values.
4. Comparative terms are not used to classify work difficulty. All classifications are numerical, eliminating judgments and providing high consistency in application.
5. It is applied to non repetitive work.
6. The system was compiled from Detailed Work-Factor.
7. It is a third-level system compatible with other Work-Factor systems.

B. Training in the Brief Work -Factor system requires from 5 to 15 classroom hours, depending on time study experience.

9.3 Methods Time Measurement (MTM)

Lowry, Maynard, Schwab searched for a means by which good methods may established in advance of production. They deduced that if operators learned the best method as they began a new task, the need for marked improvements later would be lessened. Training costs also would be lower. This would be a boon to managers plagued by production problems, labor difficulties, lack of training guides and little usable knowledge for correct methods establishment prior to starting production. They decided to study common industrial operations and endeavored to develop "methods formulas." Their initial choice was sensitive drill press operations. First, they photographed the actual shop runs of drilling operators, and also asked several seasoned raters to rate independently parts of the operation and the operation as a whole using the LMS system. Second, the film was analyzed for the motion content of the operation. Third, the consensus of ratings was applied to the frame counts to yield normal motion times. Essentially, then everyone who applies the MTM data times to motions equivalent to the well-defined

categories set up by the MTM system, tacitly agrees that the ratings of the original observers constitute a standard of normal. By applying the rating in percentage terms to the time represented by one motion picture frame it was possible to find the average time used by an average operator in the frame in question. The original research used 16 frames per second, which meant an elapsed time of .0625 seconds or .000 017 37 hour per frame. To avoid such a unwieldy time unit, the investigators proposed a time unit called the Time Measurement Unit (TMU) and assigned .00001 hour or .036 s as the value of one TMU. Since most wages are in dollars per hour, the TMU can be multiplied by the hourly rate and the decimal point then shifted five places to the left to find the cost of labor directly. Also, the hours required to produce 100 motions (or pieces) can be found by shifting the decimal two places to the left.

9.3.1 MTM-1 This is a generic, basic - level system. In the words of Schwab [1953]: MTM - 1 data establishes seven movements of the hands and arms and nine movements of the legs and body. It is a procedure which analyzes any manual operation or method into the basic motions required to perform it, and it assigns to each motion a predetermined time standard which is determined by the nature of the motion and the conditions under which it is

made.

9.3.2 MTM-2 This constitutes the second level of the MTM family with 39 time values. The system has a speed of analysis twice that of MTM-1 but a somewhat lower precision in time prediction. In developing MTM-2, frequency distributions were made of more than 22,000 MTM-1 motions collected from companies using MTM in the U.S, Sweden, and Great Britain. The distribution was found to be essentially the same in the three countries. The developers then used this information in the development of MTM-2.

9.3.3 MTM-3 This was developed by the International MTM Directorate from the same 22,000 MTM -1 motions used in developing MTM -2. The system has 10 time values and is the third level of the MTM family of systems. It has a speed of analysis that is seven times faster than MTM - 1. It can be used in situations where a less detailed methods description is required and where reduced precision can be tolerated.

9.3.4 MTM-GPD MTM-GPD stands for "MTM General Purpose Data". This system is both generic and functional in character and has data on two levels.

The generic data of the second level were derived from specific motion patterns in MTM-1, using average

distance ranges having midpoints at 1, 6, 12, 18, and 24 inches. All motions of MTM-1 are included in the elements of these data.

The functional data of the second level are contained on a second data card and pertain essentially to the use of hand tools. The elements also were developed from specific motion patterns of MTM - 1.

The third level is called multipurpose data and contains both generic and functional data. The generic elements combined the "get" and "place" elements of the second level. The functional elements cover the activities of clamping and vising.

9.3.5 MTM-C This functional clerical data system is a full clerical work measurement system at two levels of job description, precision, and speed of analysis. The system was developed by a consortium of banking and service industries.

The level 1 data are comprehensive in scope covering activities in nine areas : getting and placing, opening and closing, fastening and unfastening, filing , reading and writing, typing, miscellaneous handling, body motions, and machine operation. Level 1 also serves as documentation for level 2, which covers the same activities at a higher level. Distance ranges are

reduced to one , and codes are simplified in alphanumeric and mnemonic.

9.3.6 MTM-V This functional work measurement standard data system based on MTM-1 was developed for machine tool users. The MTM-V system is fourth level. It contains time values for handling and adjusting work pieces of any size and weight, including machine tool setup and mechanical handling equipment. The system's 12 elements are of two types : those that require hand and fingers alone and those that require the use of a handtool. This technique is supposed to be 20 times faster than MTM -1.

9.3.7 MTM-M This system is designed for use where assembly is performed under stereoscopic microscopes. It has been developed by a consortium of industrial members in cooperation with the University of Michigan. It has been proved advantageous not only for time determination but also for method improvement in this type of work.

9.4 Conclusion

Experiments have been conducted to investigate the validity of PMTS, particularly whether time standards can be determined by adding elemental times to get an accurate standard. Sanfleber [1967] proved that even great inaccuracies in the elemental times will, in many cases, lead to total times of satisfactory validity.

Gotterer [1959], a former vice-president of MTM, says :
"Any management considering the installation of a predetermined motion time system should realize that any claims made concerning their scientific foundation are unverified." Davidson [1962] says : " PMTS are not perfect, but they provide a needed technique for work measurement that is better than the other techniques available."

10. CONCEPT OF NORMAL

10.1 Introduction

There is need in work measurement for an operational definition of "normal". Work measurement literature does not sufficiently clarify the problems involved nor provide definitive guides for the establishment of normal. The concept of normal also can be extended to a fair day's work. Fein [1967] lists the following major difficulties in relation to normal :

1. When a commonly used word is selected to describe a condition, the common usage of the word may overshadow the definition. The use of the word normal to pinpoint a level of productivity or a standard causes confusion. The normal for day work and the normal for incentive may be different, even in the same plant, and this further compounds misunderstandings.

2. Misconceptions regarding normal have prevented some engineers and management from comprehending that the determination of normal is a high order responsibility of management.

3. There is no valid defense for widespread beliefs that normal is a definable point on a performance rating scale which can be transferred from plant to plant.

4. Loose definitions of the term normal can do considerable harm to management and even employees by encouraging run-away incentives.

10.2 Normal and A Fair Day's work

The following are definitions taken from the Industrial Engineering Terminology Manual [1965] :

Normal Effort -

1. The effort expended in manual work by the average experienced operator working with average skill and application.

2. Performance of an average operator over an eight-hour day under measured day conditions.

3. Performance of an average operator working at an efficient pace over an eight-hour day without undue fatigue or cumulative fatigue the following day.

4. A generally accepted industry norm arrived at by mutual agreement of labor and management.

5. Performance with a steady exertion of reasonable effort by one who has mastered the standard method. Normal pace or normal performance comes from the concept of the expected output from an average experienced operator, without the stimulus of an incentive wage plan.

Fein [1967] is of the opinion that these definitions

come up short, as they do not specify a reference standard from which to relate normal.

According to ANSI [1971] : Normal Time is the time required by a qualified worker to perform a task at a normal pace to complete an element , cycle , or operation using a prescribed method. Normal performance is the work output of a qualified employee which is considered acceptable in relation to standards and/or pay levels which result from agreement, with or without measurement, by management or between management and the workers or their representatives. ANSI definitions may be acceptable within a single plant where management and labor can develop meaningful benchmarks for defined work pace. But this approach is not feasible for multi-plant companies or for comparison between plants [Fein, 1972].

The Society for Advancement of Management (SAM) definitions are as follows [1952] :

Fair day's work : The amount of work that can be produced during a working period or shift under a predetermined set of conditions by a qualified employee working continuously and consistently at a "normal" pace.

Normal pace : The pace of a "qualified" operator working at normal tempo.

Qualified operator : An operator who has acquired a specified level of skill. A term used in wage incentives

to indicate the type of individual who will be capable of functioning satisfactorily and earn expected incentive pay under an incentive plan when he is properly motivated.

Gottlieb [1968] is of the opinion SAM 's definitions only imply that normal pace is normal tempo and thus SAM has made no effort worthwhile in defining normal pace.

The ASME definition for a fair day's work is : The amount of work that can be produced during a working day by a qualified individual with average skill who follows a prescribed method, works under specified conditions and exerts average effort [Gottlieb p.592, 1968] Here again "average skill" and "average effort" have not been defined.

The Labor Dictionary of a fair days work is : A loosely used term to describe a day's work or output turned out by the average worker who conscientiously and skillfully applies himself to his job and without deleterious effects to his physical, mental and emotional well-being [Casselman, 1949].

Fein [1967] feels that Mundel's definition of standard time, defined under Objective rating in this report, is a rational basis for normal. In comparing time standards or defined work pace concepts, the only

valid measurement base is incentive pace. Mundel's definition is deemed adequate as it requires establishment of the normal with reference to incentive pace.

10.3 Benchmarks for Normal

The following are some of the benchmarks of Normal that have been established :

1. Loading 47.5 tons of 92-pounds pigs of iron from ground to a box car [Taylor, 1911].
2. Walking at 3 miles per hour taking 27 inch steps (Presgrave) or walking at 3.57 miles per hour taking 34 inch steps (MTM).
3. Stacking 220 tons per day of 39 lb soap flake cartons [Kerkhoven, 1963].
4. Shoveling 56 tons of sand per day [Kerkhoven, 1963].
5. Dealing a pack of 52 cards on four corners of a one foot square in 0.50 minutes [Presgrave, 1945].
6. Filling a standard 30 hole pegboard using the two-hand method in 0.41 minutes [Barnes, 1980].

From a physiological viewpoint, heart rate has been used as an index of normal. Heart rate is a function of individual physical fitness, demands of work, and environmental stress such as heat. Recommendations for

an acceptable level of heart rate are summarized in Table 11. Wells et al. [1957] concluded that heart rate of up to 120 beats/min would not cause blood lactate to exceed the normal limits of rest values. Luongo [1964] claims that prolonged effort at 120 beats/min may fatigue the circulatory system. Astrand [1967] believes that age is an important variable and males of 30 years of age or older will have a heart rate of 116 beats/min or less at 50 % of aerobic work capacity. Thus, a mean working pulse of 110 beats/min appears to be a more appropriate criterion.

Table 11.

Recommended Heart Rate for Eight-Hour Workday

Source	Heart Rate (beats/min)
Suggs and Splinter [1961]	110
Muller [1962]	30 beats/min above resting pulse
Snook and Irvine [1969]	112 for leg work 99 for arm work
AIHA Technical Committee [1971]	90 - 100
Garg and Saxena [1982]	101 for arm work
Brouha [1967]	110
Legg and Myles [1981]	92

10.4 Conclusion

There is no question but that many people, including Industrial Engineers, will continue to talk about " a fair day's work for a fair day's pay." In the light of the knowledge that is available today of all the factors that influence production and productivity, it can be concluded that, "a fair day's work is anything you want it to be" [Gottlieb, 1968].

11. RATING FILMS

11.1 Introduction

As the old adage goes, "The hand is quicker than the eye." On many industrial operations, hand and arm motions take place so quickly that the observer's eyes have difficulty keeping up with them. To avoid this difficulty and to make sure he could define exactly what was taking place, Frank B. Gilbreth originated the procedure of taking motion pictures and then analyzing them very carefully.

Ever since that time, motion pictures and video tapes have proved invaluable in the study of industrial motions. Sometimes these films are used only to analyze the exact nature and sequence of the motions. On other occasions, films are used not only to compare methods of operation but also the same operation at different paces.

11.2 Society for the Advancement of Management (SAM)

In 1952, after years of research, the first SAM Time Study Rating film was on the market. The research for these films was conducted by the Rating Films Committee and the Research Division of the Society for Advancement of Management, the Research Division of the New York University School of Engineering and the Newark College

of Engineering Research Foundation. Notable among the authorities that helped prepare the film were Ralph M. Barnes, Marvin Mundell and G. Stegemerten.

All films are 16 millimeter, silent and were taken at 960 frames per minute with a constant - speed motor driven camera. There are five performance paces plus an introductory scene shown for each operation. Within each operation, the same worker appears in each scene. Instructions for the proper use of the films are contained in a Film Manual. Accompanying the Manual are tables of "true values" and a supply of observation sheets. There are three sets of rating films. The first set contains 6 reels covering manufacturing and service operations plus 1 reel each of clerical and laboratory operations. The second set of 4 rating films is devoted entirely to clerical operations. The third set of 6 rating films is devoted to the general area of production and indirect labor, and it includes element rating. The three sets illustrate on 24, 12 and 18 operations, respectively.

SAM claims that their rating films can help a company in the following eight ways: 1) Increased accuracy and consistency of production standards. 2) Decrease the time and cost of time study training. 3) A reduction in the number and length of employee grievances

over production standards. 4) Select applicants with aptitude for proficiency development in the field of time study. 5) Gauge the company's concept of a fair day's work against the industry at large. 6) Acquaint top management with the nature , significance, objectives and problems of time study. 7) Technically assist the company in evolving its own time study training, improve methodology and refine job instructions. 8) Relate concepts in these films to control "overhead" and "indirect costs".

11.3 Tampa Manufacturing Institute (TMI)

In connection with the ever present problem of securing satisfactory productivity from employees, TMI has produced instructional films. It also offers in-plant training on Fair Day Work Concepts, Manufacturing Costs for Foremen, Manufacturing Management, Methods Improvement for Foremen, More Effective Supervision, Standards Administration, Timestudy for Foremen and Timestudy for I.E's. TMI's main thrust is to acquaint foremen, plant managers, industrial relations people, union representatives and arbitrators with what should be expected in the way of production quotas. TMI claims that their films show " that 100 % performance are relaxed, business-like performances which are, in reality, quite easily maintained."

TMI has 10 different workspace rating films: "A,B, C, D, E, F, G, H, J, K" (16 mm and super-8, silent, color). Each film shows 15 different common machine, metal fabrication and electronic industry operations at workspace levels from very poor to extremely superior. TMI recommends a film on "workspace fundamentals", summarizing the metalworking and the fabricating series. TMI recommends it should be closely reviewed by seminar leaders before any of the practice rating films are used. Films listed as "workspace rating films 5,6,7 and 8 are workspace films for the sewn products industry. "Fair day work concepts" is another film which ideals with the sewn products industry.

Prof. E.B. Watmough, Director of TMI, is of the view that his benchmark rating films are superior, because according to him MTM predetermined times system levels are 17% tighter than the time standards shown in the original SAM films. He is of the view that it is possible to accurately define "A fair day's work" as it is only allowances that differ from plant to plant and not the "normal".

11.4 Other Films

The MTM Association has a library of 16 mm practice analysis films which may be adapted to rating practice.

The data package for each film loop includes an operational description, the industrial source, a complete MTM motion pattern analysis with explanations, and miscellaneous photographs and workplace layouts. Since the film speed for 100 % pace on a daywork is specified for each film, the rating trainer can use a variable speed projector to simulate different working paces with a constant work method. This latter point helps to overcome one source of possible error in judging the performance level in the films cited previously, where the method for all working cycles may not be truly constant.

Phil Carroll has about 150, 16-millimeter, black and white, silent films, each about 350 feet long, in five general types (Explanatory, Card Deal, Drillpress Burr, Card Deal & Drill Press, Industrial). The explanatory film is helpful in introducing the subject of rating. Card Deal and Drill Press seem best for basic training. Industrial operations can be used as a transition type between training and actual shop operations.

The Industrial Management Society maintains a 16 mm film rental library specifically directed to the I.E. and management fields. Films are available regarding the general concepts of rating.

11.5 Special types of rating films

In addition to conventional films the following types of film have found use in rating :

Step films - These films show step-by-step deviations from standard pace on the job, so as to establish markings on the scale of pace and to facilitate the rating. Such films are commonly made with the frames divided into different areas, each area showing a different pace, so that a group of steps may be projected simultaneously.

Multi-image films - Groups of step films are called multi-image films. Multi-image films should be viewed everyday by the time study analysts in order to keep their memories fresh as to the different work paces.

Loops - A loop is a film which is edited in such a manner so as to facilitate continuous observation by the analyst of particular elements of a operation. This enables the analyst to get a good concept of the pace being observed.

11.6 Assessment of rating films

Management's interest in rating films has been growing since SAM rating films first were made available for distribution. Rating films are intended to form a

part of a general program to assist time study analysts understand the rating phenomenon. A greater understanding of the idiosyncrasies of rating will contribute towards greater control over the rating process. Greater control will manifest itself in more accurate and reliable standards [Emerzian, 1954].

Criticism has sometimes followed the use of filmed operator performances in rating investigations. The extent of differences in rating results between filmed and "live" performance rating has been the basis of the following research.

An experiment by Margolin [1948] showed that motion pictures were rated more consistently than the "live" performances, both by element and by cycle.

Further experiments in the British Rating Survey in 16 production shops revealed evidence of greater individual consistency in rating "live" operations but the overall results were not significantly different from the survey results [Dudley, 1959].

McGuire [1958] found a significant difference in the results of carefully matched groups, one of which rated "live" performances and the other filmed performances of the same operations. The films were rated, on the average 8 % higher than the actual performances. No

conclusions were drawn by McGuire with regard to individual consistency measures.

The evidence from the previous studies appears contradictory. However, for the purpose of comparing abilities in the use of rating systems, the use of filmed performances of operations, presenting standardized conditions for any occasion, would appear to be justified.

Swalm [1959] points out an error in the SAM Film rating manual. It is the requirement that one's concept of normal pace be a function of the allowance used - in particular, that function which makes the standard time per piece completely independent of the allowances used. Stated another way, this function makes the required output per day for expected earnings independent of the allowances used.

The following are the instructions in the booklet "How to use Performance Rating Films" :

1. Determine the allowance for the operation, taking into account "such factors as personal needs, relaxation and minor delays.

2. Determine the "expected attainment." This , "expressed in percentages, represents the amount above "normal" which the average qualified operator, working at

incentive pace, is expected to be able to achieve. The commonly used figure of 125 % means the average operator is expected to be capable of producing up to 25 % above normal.

3. Enter the "Table of True Ratings" with these factors to determine the rating to be used.

These instructions to a particular example, which is summarized in Table 12.

Normal Time = Actual Operation time x True rating %

Standard Time = Normal time x (100 % + Allowances %)

Table 12

Example for using SAM manual, "How to use Performance rating films."

Actual operation time, minutes	Plant Allowance %	Expected Attainment %	True Rating %	Normal Time, min.	Std. Time, min.
.272	20	110	116	.316	.378
.272	10	110	138	.348	.382

Table 12 illustrates that the standard times obtained from having a 10 % and 20 % allowance are the same. In fact , if the allowance were to drop to zero, the results would remain unchanged. In this case the

operator would be rated at 139 % and the normal and standard times would both be $.272 \times 1.39 = .378$ minutes.

Thus there is at least one case in the literature accompanying SAM films which yields a standard time that is independent of the allowance factor.

Kerkhoven [1963] cites two work measurement experiments that indicate, "expected attainment" in two SAM films showing "sand shoveling" and "carton stacking" are too high (over 200 % higher). For dealing a deck of 52 cards into four piles, Carroll considers .45 minutes as normal while TMI considers .50 minutes as normal.

Sury [1962] has conducted research concerning comparisons between Speed and Effort rating, multi image and step film assisted techniques. His conclusions are as follows :

1. No consistent statistically significant superiority has been found for multi-image or step film rating in (1) group consistency or (2) individual flatness.
2. Use of either multi-image or step film sometimes give better results than speed and effort rating.
3. Analysis of the pace to pace change of group concept of standard performance within rating studies

showed that a tendency to under-rate a fast working speed immediately after a first slow speed, and vice versa, was apparent in all rating techniques used.

11.7 Conclusion

It has been shown that observers, using conventional rating, can have different concepts of standard performance; in measuring the rating agreement of groups formed by mixing observers from different companies the standard deviation figures are high.

If groups of this nature are tested with a film assisted technique, with the performances as shown on the standard film clearly specified, it is not surprising that closer agreement results; an apparent reduction in rating differences under these conditions may be no more than a reduction in the variation in company concepts of standard performance. This could be a valuable contribution in the establishment of national standards, but requires further examination on an individual observer basis to examine more closely the differences in the rating ability of individuals.

In the case of film-assisted systems, no evidence is available of the degree of agreement which can be expected in the application of secondary allowances. It is implied that little difference will be found. This

aspect could be worthy of investigation if significant rating improvements can be proved conclusively in these systems.

12. RATING SCALES

12.1 Introduction

There are several different rating scales in general use, and undoubtedly a competent and well-trained analyst can obtain satisfactory results with any one of them. A survey shows that the percentage system has greatest use and the point system comes next.

12.2 Rating scale methods in time study

Barnes [1980] discusses four different rating scales used in time study. Just as we can read temperature on both Fahrenheit and Centigrade thermometers although there is a difference in their scale, so we can rate operator speed whether we use percentage points, or some other unit of measure.

The first scale considers normal performance as 100 percent. The scale consists of possible ratings from 0 to 200 % in steps of 10 %. When this scale is used, it is expected that the average incentive pace will fall in the range of 115 to 145 %, and the average for the entire group will be around 130 %. This means that those operators who produce between 15 and 45 % per day more than normal will earn 15 to 45 % extra pay for this extra performance. It is also expected that an occasional

person might work at a pace twice as fast as normal. This person's performance rating would thus be 200 %, and consequently he or she would earn twice the hourly base rate. This would be a rare exception.

The second scale uses the point system, with 60 points equal to normal performance and with the average incentive pace around 70 to 85 points. The maximum expected performance is around 100 to 120 points. This scale is similar to the first scale (possible ratings from 0 to 120 points in steps of 10 points), 60 points being equal to 100 % performance rating.

The third scale is based on the premise that some time study analysts use the "average incentive pace" as their bench mark. A company might adopt 125 % as the point at which to set its "incentive time standard," and then adds 25 % to the hourly base rate in computing the amount of earnings that a person should receive at this point. Although this plan is perhaps as sound as any other, some people think it is not easy to explain to the operators and that it has no advantages over a plan using the first scale. The third scale consists of possible ratings from 0 % to 200 % in steps of 10 %.

In the fourth scale 100 % is considered as incentive performance. A few organizations use a scale having 100

% equal to "average incentive pace," and this point is usually set 25 % above normal performance. Therefore, 80 % equals normal performance on this scale. This scale consists of possible ratings from 0 % to 160 % in steps of 20 %.

12.3 Other rating scale methods

12.3.1 Conventional Rating System This method rates the individual on a number of characteristics , that is, quality of work, quantity of work, job knowledge, communications, initiative, and other job factors, according to some graphic scale. The scale consists of either descriptive phrases (outstanding, good, satisfactory, marginal, unsatisfactory) or points (1 to 10). To substantiate a rating, some formats require that the rater explain the reason for the rating.

This method is one of most popular forms because of its consistency and acceptance by raters. However, weakness of this method are:

1. Raters may interpret definitions differently.
2. Raters may tend to let the rating on one performance factor influence the rating on other factors.
3. The rating of the characteristics or factors does not provide effective employee feedback unless the rater explains the reason for the rating.

12.3.2 Behavior - Anchored Rating Scales This technique incorporates the critical incident approach, with raters participating in the development by analyzing the job as to what is considered very successful performance. Job behavior "anchors" for specific performance activities or dimensions of a job are established. The anchors for each dimension of a job are established. The anchors for each dimension then are scaled from highly effective performance to highly ineffective performance.

The advantages of behavior-anchored rating scales are:

1. Commitment of raters is greater because of their participation in development.
2. Reliability of ratings is greater because of the direct correlation with the job.
3. Provides employee feedback relating to specific aspects of performance.

The disadvantages are :

1. The time requirements for development are considerable.
2. Raters must be committed to their development.
3. Each job requires a separate format developed specifically for that job.

12.3.3 Group Judgment Method The group judgment method

utilizes an appraisal group consisting of the supervisor of the employees being judged, two or three supervisors who have knowledge of the job performance of these employees, and a member of the administrative or personnel staff. The group discusses job duties, performance standards, actual performance of the incumbent, causes of performance, and ideas for improvement and defines a specific action plan for performance improvement or employee development. The ratings given then are based on the consensus of the group.

One advantage of this method is that by using several raters the validity of the appraisal is that the multiple raters tend to provide better ideas for improvement of performance than would be a single supervisor. On the negative side, the process is very time consuming.

12.3.4 Assessment Method The objective of the assessment method is to predict employee's potential for promotion and the future performance of candidates for hire. A number of candidates are brought together for several days in work environment situations, which may include tests, games, or exercises simulating actual situations that would be encountered on the new job. Trained assessors observe behavior, make judgments, and prepare a

final evaluation of each candidate.

The assessment method has good validity in predicting future performance. The obvious drawbacks are the costs associated with developing a professionally designed program and the heavy commitment of time on the part of both assessors and participants.

12.4 Rating Scale Errors

Mundel and Lehrer [1948] have suggested a scaling factor of at least 6 % . Murrell [1974] states that the highest pace change at which discrimination of 5 % is likely to be reliable is 80 - 85 % . So he finds it hardly surprising that rating even 100 % (normal) is sometimes unreliable. Emerzian [1954] points out that the significance of a rating scale error is a function of its position along the rating scale. Thus a 5 % rating error at the 40 % level ($(45 \% - 40 \%) / 40 \% = 12.5 \%$) is more significant than a rating error of 5 % at the 160 % level ($(165 \% - 160 \%) / 160 \% = 3.13 \%$). Kannon [1969] suggests a rating scale of 80 % to 140 %, with intervals of 10 %, as it gives a total of seven intervals which he claims adheres to the information processing limitation of 7 categories for humans. He states that the use of a rating scale with more than 7 intervals would lead to inaccuracies in rating.

13. FACTORS AFFECTING RATING

13.1 Introduction

The time study analyst involved in the "rating" process should recognize the fact that since no adequate definition or measurement of "normal" is yet available, the analyst should take into account the various physiological, psychological, and other factors which affect the performance of an operator in the industrial environment. An attempt is made here to comment on the effect of some of these factors on operator's performance.

13.2 Age

There has been and still is an immense amount of research interest in human ageing, covering changes in physical as well as mental functions. Evidence available suggests that the ageing process, in so far as it may effect industrial efficiency, can begin to show itself in certain circumstances at ages as low as 35, and that unless changes in ability with age are taken into consideration for individuals over the age of about 40-45 years, the optimum use will not be made of the work force [Murrell, 1965]. However it should be pointed out that the evidence of decline in output with age is distinctly scanty. McFarland and O'Doherty in a chapter in Birren

[1959] quote two studies, neither of which show any output decline. On the other hand some other studies have shown that there is a performance decline with an increase in age. Murrell and Edward's [1963] experiment on two younger and two older tool room turners using two different measuring devices showed that the cutting time for the older men was less than that of the younger men under both conditions.

A number of studies have suggested that any slowing of output rate which does take place will occur first in the perceptual elements of a task, rather than in the physical movement which a person may make. Murrell and Forsaith [1960] could find no difference in times of bodily movement between older and younger men. Perceptual elements usually are too short to be timed, but cumulatively they may produce a loss of productivity. But, for some time before this occurs, experience may enable older men to achieve satisfactory performance by an economy of force and action which will help to compensate for any slowing down. Griew and Tucker [1958] found that older men appeared to be able to achieve the same results with fewer control movements than younger men working on similar machines. Murrell et al [1962], showed that, in pillar drilling, the performance of older naive subjects was substantially worse than that of

young naive subjects, but the performance of older professional drillers obtained from industry, was if anything , slightly better than that of young drillers. This clearly demonstrates the role of experience in compensating for increasing age.

Four factors which are typical of job components, which may influence or be influenced by the various biological changes which take place with age are :

1) Loss of visual acuity, accommodative power and pupil size may affect the size of detail which can be seen and the ability to read fine scales. While to some extent these losses can be offset by increased lighting and by the use of adequate optical aids, it would seem that very fine work is probably unsuitable for old people.

2) A decrease in the speed of discrimination and in the speed of making decisions.

3) A loss of short term memory and a tendency for greater variability.

4) Reduction in channel capacity which affects the rate at which older people can receive information, which in turn may effect the speed of machines upon which older people have to work.

The effect of increased variability with age is most likely to be found on paced tasks. This has been shown

experimentally by Brown [1957] to be the case. Studies in industry carried out by Shooter and Belbin (reported in Welford [1958]) shows that on jobs with time stress, there was a substantial deficiency of men over the age of 45 and in women over the age of 40. Welford [1958] makes the suggestion that another factor may enter here. If the work is paced in a way that causes signals for action to occur at times which are not of the subject's own choosing, and if responses have to be carried out within a defined period, breakdown may arise because of the limited capacity for information transfer and short-term retention which, at high speeds, may be overloaded. Under these circumstances, responses may lag further and further behind the signals, until blocking takes place. The effect of piecework and bonus schemes on older workmen is an aspect of pressure for speed which is not quite so obvious. Murrell and Forsaith [1960] have shown that it is improbable that the slowing down of older men would be shown up by stop watch studies of element times, so that the normal process of rate fixing will usually be unable to take age into account. Murrell [1965] says that predetermined time systems also seem to have as a datum the performance of younger people, so that the time values which will be set, since they do not account for the perceptual components of work, will not truly be representative of performance which can be expected from

older men. The method of payment and the need to maintain a comparable earning level with that of younger people may put time stress on older men which they may find in time to be intolerable. This may be a form of 'added stress' which may have the effect of reducing performance. Thus older people may put up a better performance on the same job if they are not on piece work than if they are.

According to Welford [1962], experiments comparing performances at several related tasks having different degrees of difficulty have three distinct patterns of slowing with age. In some the extra time taken by older subjects could be represented by the addition of a constant to the time taken by younger people for both simple and more difficult tasks. In others, the times taken by older people have risen in fairly strict proportion. In yet others older subjects have taken quite disproportionately longer over the more difficult tasks.

Rhodes [1983], in a recent review of studies of the relation between age and performance, said that there were approximately equal number of studies reporting that job performance increases with age, decreases, or remains the same. She concluded that the relation between age and job performance may depend on the type of performance being used, the demands of the job, levels of individual

experience of those being evaluated, other sample characteristics, and potential unreliability in measurement instruments. In short she concluded that the evidence is 'mixed.'

Waldman and Avolio [1986] point to the fact that, over the last 30 years, fewer than one study of the age/performance relation has been published per year. Chronological age will be used as a occupational qualification by those decision makers who accept the premise that individual capabilities decline with age.

13.3 Fatigue

Allowances and rating are strongly related. Generally, analysts tend to give lower allowances for looser rating and vice versa. Karger and Hancock [1982], say a fatigue allowance is required if any of the following conditions exist :

(1) The metabolic energy demand of the job exceeds certain limits. This is considered whole body physiological fatigue.

(2) An adverse environment (such as heat stress) exists that results in unhealthy physiological changes to the body.

(3) The work place requires repetitive use of the same muscle groups. This is called local muscle fatigue.

Should the fatigue allowance be an allowance for an actual rest period or should it merely be added to the standard on the assumption that it is a compensating device for a necessary change in pace ? Must a solution wait until the physiologist and psychologist can inform the engineer just what objective criteria of the phenomenon are available and how they can be measured ? It is only when this basic information is forthcoming that engineers can begin to talk about an objective scientific allowance for fatigue in their rate setting techniques.

Taylor [1911] , in his classic description of the time study technique that established the foundations of modern time study methods, made a combination factor of fatigue and downtime one of the principal variables in measuring a correct production rate. Holmes [1938] defines fatigue "as the overuse of the mind or muscles, resulting in lack of energy and an inability to continue a set pace or speed."

Just how the fatigue allowance should be divided between a share for change in pace and a share for actual rest periods remains an open question. Vernon [1940] has demonstrated that rest periods markedly improve output even for jobs requiring a minimum of physical exertion. They seem particularly effective on repetitive jobs where

they afford a relief from boredom. But here again there is an implied assumption that the comparative output is an adequate index of fatigue.

Rayan [1952] suggested using the concept of effort for accounting for fatigue allowance. He defines effort subjectively as follows : "By effort we shall mean an individual's experience of how hard he is working." He recognizes that some more objective physiological test is necessary as an indication of fatigue. He suggests that the answer may lie in researches on the correlations between the level of muscular tension and the electrical discharges in the muscle tissue. He also suggests possible correlations between suggested levels of activity and the electrical resistances of the skin.

Many of the problems and health hazards involved in grocery order selection performed under time standards are discussed by Garg, Hagglund and Mericle [1986]. The authors of that study found that most selectors experienced excessive fatigue; they concluded that grocery warehouse production standards based on time and motion studies or predetermined time systems were physiologically unacceptable. Recommendations for additional fatigue allowances were based on the conclusion that "a significant number of workers may not be able to meet those standards as they might be working

close to their maximal capacity for this type of work. This is especially true for the female and older work force."

Analysis of the time-and-motion data used to develop six grocery production standards by Karnes et al [1986] provided evidence of inaccurate assignment of performance ratings, diminished work capabilities for older and female order selectors, and failures to include relevant variables that affect selectors' performance of certain non pick and travel task elements. Performance ratings had very low correlations with observed performance times; collectively they accounted for less than 10 % of the variance in observed times.

Once an objective measure of physiological tax has been developed, then many other problems will open up in terms of the long-run effects of work upon the operator in the machine-system. The point at which the physiological sources of variation merge into the psychological sources of variation is not clear cut. While reviewing the subject of fatigue , investigators have even attempted to define the concept of the state of mind. The next section will be devoted to these psychological sources of variation.

13.4 Psychological Factors

The emphasis on the necessity of standardizing the job pattern before attempting to make a rating has been pointed out before. The question that must be answered is : To what extent can the motion pattern of a job be standardized ? Some enthusiasts since Gilbreth's day have gone further in breaking down jobs into elemental motions than did the original masters. Olsen [1946] states that Gilbreth's therbligs could further be subdivided into "movements" which may be defined as the muscular reaction required to move a part of the body. However, in contrast Farmer [Uhbrock p.3, 1935] asserts that "the actual method finally adopted by the worker must be the one which he finds the most convenient; that is, the one best suited to his physical and psychological makeup.

Myers [1925] points out that Gilbreth's notion 'of the one best way' is impossible to carry out in practice, because no two workers can be trained to precisely the same features of rhythm and movement. Thus in standardizing a job one should not be governed by the therblig structure of the method, but recognize that different methods differ for different people within certain general limitations, laid down as a series of motion principles by Myers. If a worker's movements are analyzed, it is found that they fall into three classes:

1. Those strictly necessary for the work.
2. Those due to the worker's adaptation to rhythm of movement.
3. Those due to inexperience and poor workplace arrangement.

It is quite obvious that Class 2 will lead to variations in method as individuals differ. Without any examination of the principles of motion economy that Myers proposes for the correction of class 3, we may conclude that the standardization of methods in class 2 represents the first great threat to the concept of a constant chance cause system creating a common population for the performance of groups of people. It does not interfere with our ability to predict future performance of the idealized individual in the idealized factory.

However, this question of predictability of an individual's performance must be time studied on the assumption that the individual always performs the job exactly the same way. This raises the whole question of the psychology of monotony. Under the circumstances, the analyst would select a worker who does not require a change in work pattern to relieve monotony. Inasmuch as this postulates an ideal man-machine situation in an ideal factory, it should be recalled that the purpose of time study is to set standards among the workers found on

the job [Barmack, 1912].

If the analyst succeeds in releasing the motivating force of the operator being studied completely, then time study for rate-setting purposes would be a very simple problem. Gomberg [1955] is of the opinion that aside from the fact that the motivating force released by the financial incentive is limited in degree, within a short time after its introduction it becomes relatively ineffective. Motowidlo et al [1986] are of the opinion that frequency and intensity of job stress can lead to depression which in turn causes decrements in interpersonal and cognitive and motivational aspects of job performance.

An analyst usually observes a task several times before using judgment in determining a rating factor. Murphy et al [1986] studying the effects of subsequent performance on evaluations of previous performance, are of the view that raters are biased in favor of recalling behaviors that are consistent with their general impression of a ratee and that subsequent performance may systematically alter the rater's recall of the ratee's previous behavior. The emotional cycle has an unpredictable influence on the motivator drive. Hersey [1932] found that there was a definite periodicity to the emotional tonus of twelve men whom he studied for a

year, which could not be accounted for by environmental happenings, climatic changes, or physical conditions, but which definitely affected the feeling of effort and performance on the job.

It is important to remember that these psychological forces are just as real in the work situation as any physiological limitation. They cannot be dismissed as pure emotional bunk as many time study analysts have attempted to do.

13.5 Effect of Environmental Conditions

Consistency, which is one of the major elements of dissent in the measurement controversy includes the conditions surrounding the measurement. If conditions are not standard over time, even technically exact measurement will show differing results. This source of error can be partially controlled by insistence upon rigid adherence to original conditions. However, as a matter of practical fact, this is rarely attainable, as the plant is older, and so is the equipment and nothing is ever really "like it used to be."

13.5.1 Temperature Temperature and humidity affect workers in industry in a number of ways. In ordinary jobs, the temperature of the work room may influence the

efficiency and/or safety of the workpeople. Extensive studies by Mackworth [1950] and Pepler [1958] suggests that skilled performance would deteriorate sharply if the effective temperature passed beyond the region 27 to 30 degrees Centigrade. McFarland et al [1954] has established that manual dexterity at temperatures which can be withstood in normal clothing fall off markedly below 10 degrees Centigrade. If accidents reflect in any way the effect of temperature on efficiency, then it might be taken that older men are adversely affected by higher temperatures. Osborne and Vernon [1922] have established that there is an increase in accidents both with the decrease and increase of temperature from an optimum of 19 to 20 degrees Centigrade, the increase with cold being somewhat greater.

13.5.2 Noise It is interesting to note that noise is probably the only industrial disability for which compensation can be paid which will not necessarily affect earning capacity. It may even improve the efficiency of the victim since hearing loss in the higher frequencies above those involved in speech may improve an individual's ability to hear speech in a noisy environment [Murrell, 1965].

Continuous noise, if it is broad band, may have an effect which is related to its intensity. If it is

narrow band and the frequencies are near the top of the spectrum, it may cause irritation (and, indirectly, inefficiency) which may not be directly related to its intensity. Intermittent noise, if it is regular, may have effects which differ little from those of continuous noise, but if it is irregular and unexpected it may cause a "startle reaction" which can be most disturbing. The influence of meaningful noise will be related to a large extent to particular circumstances and is likely to depend on the nature of the noise and what it means to the hearer.

13.5.3 Visual Environment The majority of industrial tasks will depend for their efficiency on adequate vision. Therefore lighting may play an important part in determining the efficiency with which tasks are carried out. Other factors which may be of importance are the contrasts between the surroundings and the task, which may be influenced by color and the presence or the absence of glare.

The amount of light required for the performance of a task is dependent on 1) the size of the object, 2) the contrast between the object and its immediate surroundings, 3) the reflectivity of the immediate surroundings, and (4) time allowed for seeing.

Even if the Westinghouse system is justified in making provision for conditions to be leveled, the time study analyst should be very familiar with the effect of the above factors on performance, if the analyst is to ascribe the correct numerical weights for the conditions in which the task being rated is performed.

13.6 Learning

The learning curve was first recognized in the aircraft industry where any reduction in the considerable number of direct-labor hours needed for assembly work is quickly recognized and formalized. Belkaoui [1986] states that the learning curve theory is based on a simple principle of human nature : People learn from experience. Belkaoui adds that the basic doctrine of the learning curve can be summarized as follows :

1. Where there is life, there can be learning.
2. The more complex the life, the greater the rate of learning. Man-paced operations are more susceptible to learning or can give greater rates of progress than machined-paced operations.
3. Alchian [1958] states that the rate of learning can be sufficiently regular to be predictive. Operations can develop trends which are characteristic of

themselves. Projecting such established trends is more valid than assuming a level performance (no learning).

Industrial engineers have long recognized that learning takes time . Consequently, it is much better to conduct a time study on an experienced employee than on a new one who has not become proficient and who would necessarily have to be leveled lower. In rather simple work, such as light assembly involving relatively few parts, an operator can become very proficient in just a few days. In other situations where work is complex, it may take several weeks before the operator can achieve coordinated mental and physical qualities enabling the analyst to proceed from one element to the next without hesitation or delay.

It is desirable for a company to plot learning curve data for the various classes of work being performed. This information can be quite helpful in determining when it would be desirable to conduct a study and also can indicate levels of productivity that can be anticipated as additional learning takes place. Data for the learning curve (which tends to be hyperbolic) can be plotted on logarithmic paper, thus linearizing the plotting. The analyst should recognize that experience in similar work can provide learning on subsequent and different work. A new turret lathe operator may need a 3

week experience on a job before his or her learning curve begins to "flatten out". However, an experienced turret lathe operator may need only 3 days for his or her learning curve to flatten out on the same job.

Learning curve theory proposes that, when the total quantity of units produced doubles, time per unit declines at some constant percentage. If, for example, it is anticipated that an 85 % rate of improvement will be experienced, then, as production doubles, the average time per unit will decline 15 %. Typically, the learning curve is a hyperbola. Cochran [1960] is of the view that the learning curve would not be of direct use in a mass production industry due to the impact of standardization, mechanization, long productions runs and widespread competition on components.

The learning curve should prove a useful tool to the time study analyst to determine exactly when time standards should be audited. However, the analyst should keep in mind that the operators should not be physically and mentally strained when updating time standards. This is particularly true of a company paying incentives, more so when every rejected unit produced by an operator is deducted from wages.

13.7 Other factors

Hamilton et al [1969] have determined that the design of the job is a significant factor in determining the physiological cost to the worker. Different designs for the same job will indeed result in different physiological costs for the same work output. This finding casts doubts upon a fairly implicit assumption made by many industrial engineers - namely, that the same fatigue allowance is appropriate for similar tasks providing that the tasks are equal in duration and work output. In considering situations where pace and weight can be varied at the discretion of the job designer, a guideline offered is : use heavier weights at slower paces. It is the responsibility of the analyst to determine that the job design is adequate before he doing the rating.

The various established benchmarks for normal indicate that every task has a most efficient pace. Barany et al [1960] have established that the proportionality effect of job difficulty is significantly different at different paces. Das [1964] is of the opinion that unfamiliar or complex operations caused rating errors of greater magnitude and while slow paces resulted in loose ratings, fast paces resulted in tight ratings. Mansoor [1967] is of the opinion that when

observing several paces the usual tendency for time study engineers is to rate "flat". It also should be noted that some industrial tasks are paced so that worker productivity is forced by the rate at which materials necessary for the task are provided.

Studies done by Anastasi [1958], Garai et al [1968], and Tyler [1965] indicate that, for tasks requiring finger dexterity for fine manipulation, the performance of females were quicker than of males. LaTorre et al. [1976] demonstrated that females on the average needed only 83 % of the average time required of males to complete the O'Connor Finger Dexterity Test, First half. The structure of the female hand and the greater sensitivity of the female to touch contribute to this performance capability. Karnes et al [1986] have established that for warehouse operations, females worked at a reliably lower performance level (95 %) than males aged 21 to 45 (102 %) based on collected data for 12 months.

Andrews et al [1967] investigating the influence of the duration of observation time on performance rating of dealing a pack of 52 cards found no statistical significance of the influence of observation time on the precision of the performance ratings. The results of this study indicate that experienced time study analysts

need not dwell while making performance ratings. However, since only the single task of dealing cards was examined, there is need for further research.

13.8 Conclusion

It would seem that establishment of a work standard can be best done when the worker and the company understand each other's interests and goals. Final acceptance of a given work standard, however, depends upon a continued willingness on the part of the company to offer a full explanation of their methods of standards setting to the affected workers.

14. TRAINING IN RATING

14.1 Introduction

Practice in the rating of walking and the rating of dealing of cards serves to show the importance of performance rating in time study work. Such rating studies may well be included in all time study training programs. These studies also are excellent for training beginning time study analysts and for improving the rating ability of experienced industrial engineers.

The key to good time standards is regular training in performance rating by all practicing time study engineers. The time study analyst is expected to regularly establish standards within $\pm 5\%$ of the correct standard (which is really never known). However, if the analyst is able to regularly performance rate films or videotapes depicting operations characteristic of his or her plant within $\pm 5\%$ of what has been agreed upon as being a certain performance, then it is highly probable that the analyst will maintain a record of setting standards that will be accepted by both labor and management.

14.2 Accuracy in Rating

Barnes [1980] has made the following general

statements concerning training in performance rating.

1. An individual's accuracy and consistency in performance rating can be improved through proper training.

2. An individual can rate more accurately on performances that are close to normal. There is some tendency to rate too high on slow working speeds and too low on working speeds that are considerably above normal.

3. On simple work (free and unrestricted motions) a person can rate a motion picture film of an operation about as accurately as the operation itself.

Lifson [1951] suggests :

1. The concept of a normal working pace can be readily changed.

2. Potentially consistent observers can be selected before training as rating ability can be tested.

3. Ratings made by three observers collaborating are more consistent than ratings made individually.

The ease with which the concept of normal effort can be changed emphasizes the need for a lasting and accurate record of normal effort. Moores [1972] states that variability in rating can be reduced by improved rating and more frequent checks on ability. Anson [1954] states to improve accuracy in rating, the job studied should be accurately specified and the method employed accurately

defined.

The basis of all methods of analyzing time studies is that rating is inversely proportional to the actual time taken. Desmond [1950] has designated the reciprocal of the rating multiplied by a constant, the latter so chosen that normal performance is represented by the figure 100 in all scales, as the "reciprate". Consequently the basis of the analysis may be restated in the form reciprates are directly proportional to the actual time taken. Thus, when reciprates are plotted against the actual time, the plotted points should lie on a straight line passing through the origin. This line is called the operation line. In practice, recorded ratings will be scattered about the operation line. The degree of scatter about the estimated operation line can be used as a measure of the ability of an analyst to rate consistently.

"Flatness" in rating results when low performances are over rated and high performances under rated. "Flatness" in rating indicates that the raters are totally unsure of their estimates, they try to play a conservative role by hugging the normal. Reasons for "flatness" can be very short duration of observation, operations which are slow and heavy or operations where movements are too minute.

Lifson [1953] made the following conclusions regarding errors in time study judgment of pace.

1. Pace ratings involve considerable error.
2. Some raters rate higher than others.
3. Some raters are more consistent than others.
4. Some workers are rated higher than others, even when all perform the same jobs at the same paces.
5. Normal pace is rated most reliably.
6. Some jobs are rated more reliably than others.
7. Workers' judgments on equating the jobs differ from the pace ratings of the time study analysts.
8. Not all raters followed the pattern of underrating high paces and over rating low ones.
9. Some workers can judge more reliably than time study analysts can rate.
10. On a job which a worker rated relatively high, the worker would be rated relatively high and on a job which a worker judged relatively low, he would be rated relatively low.

14.3 Rating techniques

The most extensively used training technique in performance rating is the observation of videotape or motion picture films illustrating a variety of operations characteristic of those being performed in the company. A complete range of the performance scale should be

demonstrated by the video tape or films. Each viewing will have a known performance level, and immediately after it is shown on the screen, the various trainees will rate the performance independently. Their respective ratings then will be compared with the known ratings. For those analysts who deviate substantially from the known rating, the operation will be reshown and discussed at to the rationale for the correct rating.

Niebel [1982] expects a time study analyst who is thoroughly trained to performance rate within $\pm 5\%$ of the correct rating as long as the performance being demonstrated is somewhere between 0.85 and 1.15 of the normal. If the performance of the operator is outside this range, it becomes increasingly difficult to performance rate accurately.

A motion picture film of an actual operation may be formed into a continuous loop and projected at constant speed for rating purposes. Considerable use is being made of such film loops for practice in rating and for time study training purposes.

Das [1965] recommends a three step programmed learning approach. In the first step raters are first given some background information on the fundamentals of performance rating. Das's recommendations are :

1. With elemental times shorter than .05 minute, it is not possible to exercise careful judgment for a succession of such elements.

2. In the shorter cycles, consisting of only a few elements, all of which are familiar to the operator, assign one rating to the entire study.

3. In a particular operation, the operator performs the familiar elements proportionately faster than the new elements in the cycle. Assess the performance of the elements separately.

4. Where the machine controls a portion of the cycle and the operator can do nothing to change the time required to perform that function, assume the rating for this period to be 100 %.

5. Avoid systematic bias or error in a particular direction.

6. Do not overrate poor performances and underrate excellent performances.

7. Avoid the anchoring effect i.e. do not let the previous operation or performance bias the subsequent operation.

The second step involves showing normal performance in various operations.

The third step involves combined testing and training. The rater was asked to rate a performance just

viewed. If the rater's rating was within $\pm 5\%$ of the true rating, the rater was informed that the rating was correct and was allowed to view the next scene of the same operation. But in case of a wrong rating (outside $\pm 5\%$), the film was rewound, the correct rating given to the rater, and about half the same scene was shown again to give the rater further training.

Reuter's [1977] programmed learning approach with regard to using SAM films for training raters follows the same guidelines as Das's programmed learning approach. He suggests showing the pace closest to normal first and then higher paces in ascending order. During the first rating session, the films were stopped halfway through each scene, and the observers were asked to rate each scene, based upon their concept of normal. Then the students were given the true rating and shown the second half of the scene for reinforcement of the true pace rating.

Thornton [1980] recommends that instructions explaining the task, encouraging careful observations and more important instructions on the avoidance of systematic errors helps in improving observer accuracy.

14.4 Conclusion

The company should require regular training of all

its time study analysts. This will help ensure not only the validity of developed standards, but also the consistency in rating between the various analysts as well as the improvement in consistency of each analyst with reference to his or her own work.

The company should have access to an extensive library of rating videotapes or films. Greater flexibility in use of the company visual aids can be obtained by showing them at different speeds at the various training sessions. Thus the analyst will not be able to depend on his or her own memory as to the rating of a particular film, since the rating that it demonstrated on its last viewing will be different from the rating of the present viewing.

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**A SURVEY OF PERFORMANCE RATING RESEARCH
IN WORK MEASUREMENT**

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AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department Of Industrial Engineering

KANSAS STATE UNIVERSITY

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1988

Two very important but highly controversial factors in work measurement are rating the speed, pace or tempo at which the subject of study is working and the establishment of a normal or standard speed for a specific task. Work measurement rating is important because rating of operator performance was involved in the normalising of performance times of most predetermined time systems as well as being used in time study.

The advantages and disadvantages of the various rating systems are evaluated. Standards established for normal performance by organisations such as MTM (Methods Time Measurement), Work Factor, etc. are compared. Whether compatibility of standards exists for tasks involving hand and foot motion is examined. The influence of various factors such as age, gender, and learning is discussed. Finally, training methods for rating are discussed.