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ABSTRACT

This is an activity-oriented guide for general mathematics classes, grades 8-12. Mathematics used includes measurement, estimation, time, computation, ratio, and money. Students assume the role of an industrial engineering technician determining the amount of time allowed and operator pay for completing an operation on a production line. A deck of playing cards, a clipboard, a stopwatch, and graph paper are needed. The term "piece rate," related with other pay methods is explained, using an example. The method to set the piece rate is described: (1) breaking the operation into parts; (2) setting quality standards; (3) developing workplace layout; (4) developing methods; (5) determining time allowed; (6) considering other costs; and (7) assembling this information. Other uses, such as time and motion studies, and equipment justification are discussed. Figures of the stopwatch, time-study board, worksheets, seven exercises, and three projects are presented. Benchmark for hand movement, benchmark for walking, setting a base rate, and manufacturing company forms are provided in the appendices. (YP)

Piece Rate

Applications of Industrial Engineering
for the Mathematics Classroom

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Teacher Notes

Piece Rate is an activity oriented application designed for general mathematics classes (grades 8-12). Mathematics used includes measurement, estimation, time, computation, ratio (scale drawings), and money.

The context for the mathematics involves the students assuming the role of an Industrial Engineering Technician (Time Study Technician) determining the amount of time allowed and operator pay for completing an operation on a production line.

The example provided involves the assembly of a BIC-type ball-point pen. The students are introduced to the concept of incentive pay, then led through the processes of establishing the nature of the operations necessary in a production operation to assemble the pen from its component parts and determining the cost and operator pay involved in the operation.

Exercises are supplied to provide practice on the various component operations. Project-type exercises are included to provide students opportunities to simulate the entire process.

Equipment

You will need a deck of playing cards, a clipboard and a stopwatch in addition to copies of the forms provided and graph paper. The activity assumes the use of a standard stopwatch of the kind found in most high school athletic departments. The use of calculators for computation is strongly recommended.

References

Karger, D. W. & Bayha, F. H. (1961). Engineered Work Measurement. New York: Industrial Press.

Niebel, B. W. (1955). Motion and Time Study: An Introduction to Methods, Time Study, and Wage Payment. Homewood, IL: Irwin.

Vaughn, R. C. (1985). Introduction to Industrial Engineering. Ames, Iowa: Iowa State University Press.

Most college bookstores or libraries will have an introductory level Industrial Engineering text and/or references similar to the ones listed above. Perhaps the best resource is an Industrial Engineer or Time Study Technician from a plant in your area.

PIECE RATE

You are looking for a summer job, so you go to the Acme Widget Company and put in your application. The personnel manager, impressed with your credentials (especially the A in math), calls and sets an interview date. The day arrives and, after filling out an indeterminable number of forms and taking several tests, you begin your interview. Your first question is "How much do I get paid?"

The personnel manager explains, in one breath, that "You will be a Set Right Sprocket operator. Your base rate is $4.80 per hour, with a piece rate of $3.60 per hundred for BV42 Widgets, $3.75 for DG23's, and $3.50 for LW21's. Wait time is paid at minimum, other work at average if there is work on your job and at base or average, whichever is lower, if not. The rest you'll pick up as you go along." Not wanting to seem unknowledgeable in front of the person who controls your future employment, you nod knowingly and accept the job when offered.

You rush home excitedly to tell your family the news. Their first question is "How much will you make?" You smile, again knowingly, and reply "It depends on whether the sprockets are red or green" and exit quickly.

How Much Do You Make?

There are many ways to pay someone for doing a job. You are probably familiar with at least three: hourly wages (with overtime at time-and-a-half), salary (per week, month, or year), and commission (a percentage of sales). Although these forms do represent some of the ways people are paid, many others (especially in manufacturing, textile and apparel, and automobile repair) are paid on a system know variously as "piece rate", "incentive pay", or "flat rate" - where a fixed amount is paid for each unit completed. In theory, an operator working on an incentive pay system will work 20% faster than an equally skilled operator paid by the hour (this is also known as the "greed factor").

For example, a mechanic may be paid $18 for a simple brake alignment on a 1986 Ford Escort, whether the job is completed in two hours or in fifteen minutes. This rate has been calculated on the average time taken to complete the job by a trained mechanic working at a "normal" pace using a standard procedure. These rates are formulated by "time and motion study" and are typically under the control of an Industrial Engineer.

In the Acme Widget Company example above you would be paid on a combination of rates. Piece ate (named from the concept of paying so much for each "piece" completed) is paid while you are "on the clock," or working on your specified job for the predetermined rate per hundred units produced. For example, you are paid $3.60 for each 100 BV42 Widgets on which you set the right sprocket--regardless of how long it takes you to do so.

The remaining "off the clock" time (when you are not setting right sprockets) may be paid in several ways. In this example you are paid at the prevailing minimum wage rate ($3.35 per hour) if you are sitting waiting for work (your supervisor will tell you to "clock off" using the nearby time clock).

If, however, your supervisor asks you to do other work while you are waiting you are paid at your "base rate" of $4.80 per hour or at your "production average" (usually shortened to just

"average"), whichever is less. A "base rate" is assigned to a certain job based on the difficulty or skill level required on the job and the anticipated learning time. This rate plays an important role in determining the piece rate, as we shall soon see. Your "average" is the average amount you earned while "on the clock" for the previous pay period (usually one or two weeks).

If there is work on your job but you are needed more on another, you are paid at your "average" for this time.

Consider the following example: You start work at 7:00 A.M. on your assigned job. You work until 10:30, setting the right sprocket on 250 BV42 Widgets, 200 DG23 Widgets, and 180 LW21 Widgets. You run out of work, punch the time clock and sit idle for 30 minutes. Then your supervisor asks you to help out on the "oil left sprocket" operation until lunch (12:00). After lunch (1:00) you return to your regular job until 2:30, producing another 240 BV42 units. Your last hour and a half is spent again oiling left sprockets, but now there are right sprockets to be set.

Assuming your previous average pay earned while setting right sprockets over the previous two weeks is $5.20/hour, your pay is calculated as follows:

7:00 - 10:30	250 BV42 @ $3.60/hundred	=	$ 9.00
	200 DG23 @ $3.75/hundred	=	7.50
	180 LW21 @ $3.50/hundred	=	6.30
10:30 - 11:00	minimum ($3.35/hour)	=	1.175
11:00 - 12:00	base ($4.80/hour)	=	4.80
12:00 - 1:00	(Lunch)		
1:00 - 2:30	240 BV42 @ $3.60/hundred	=	8.64
2:30 - 4:00	average ($5.20/hour)	=	7.80
	TOTAL	=	$ 45.22 (rounded)

Your average "on the clock pay is $6.29 per hour ($31.44 for 5 hours) - keep this up and your "production average" will be higher in the next pay period.

Your average is sometimes stated in terms of an efficiency rating computed as a percentage of base rate (e.g., 6.29/4.80 equates to approximately 131%). Don't forget that after state and federal (and possibly city) taxes, social security, and health insurance charges, your take-home pay will be less.

The actual payroll sheet will look much more complicated that these calculations with some categories in red ink, others in blue, and so on. For example, your earnings while "oiling left sprockets" in the afternoon will reflect not just the $7.80 you were paid but shows the amount of piece rate work you completed on that job (say it paid $2.40 per hundred and you completed 200 for a total of $4.80) with the extra, in this case your $7.80 less $4.80 = $3.00, listed on the payroll sheet as "make-up."

This does not affect your pay, but is a critical figure to the manager who wants to know how much of total earnings were piece rate earnings and how much were other forms of pay. Managers are expected to schedule work to minimize non-piece rate earnings.

In a situation where there are dozens of operations, each with several rates, a good payroll clerk is worth his or her weight in gold.

How Is The Piece Rate Set?

Obviously, an essential part of this system from both the employer's and employee's standpoint is the setting of the piece rate. But while the "set right sprocket" rate is probably most important to you this summer, it is only a part of a process that begins with the "costing" of a proposed new product. To describe this process, let's propose the following scenario.

You are a new Industrial Engineering Technician, working for Bates Manufacturing. The marketing department has decided to offer a new line of specialty items and you have been asked to determine the cost and manpower requirements for one of these items--a ball point pen that is to be given out by salesmen as a gift/advertising gimmick to their customers. Note that the pen is the non-click, BIC-type.

Your plant will receive the parts for the pen from several different locations. The base of the pen has been sent to the printer for application of the company logo; it arrives in boxes of 10,000. The refill part (holding the ink) arrives in separate boxes of 10,000; the cap arrives in a third box containing 50,000 each; the small piece that covers the open end of the base arrives in the fourth and final box with 250,000 pieces per box.

Your job is to describe the process of assembling the pens that your production workers will follow, listing the equipment and operators needed and the cost per pen of assembly. Remember that you must ship a total of 50,000 of the pens in boxes containing one gross (144) each to your first customer--IMB. Marketing estimates that business will eventually run at a rate of 200,000 pens per week.

Breaking the operation into component parts

Your first task is to decide the nature and sequence of the jobs to be performed. Do you want each operator to assemble a complete pen or, do you want one operator to insert the ink cartridge then pass the sub- assembly to the next to add the cap, and so on? Will the operators get their own components or will someone supply them with parts (getting up and moving around is time-consuming)? How will they know when 144 pens are completed or, can you come up with some ingenious (and inexpensive) method of counting and boxing the finished pens?

Let's assume we have decided to have each operator completely assemble a pen, boxing the finished product at the workstation. In fact, there is no need for the assembler to move--parts and supplies will be furnished (initially by a supervisor/quality checker/parts person/packer; as the number of people on the job increases there will be separate people to perform each of these functions). Remember, the less the operator has to do, the more pens each operator assembles.

Setting the quality standards

First things first. No job begins at Bates Manufacturing until the quality standards are set. This includes a written description of the requirements as well as a description of the sampling methods used to determine whether or not the standards are being met. Nothing will lose your customers faster than a pen with the ink cartridge inadvertently left out or the company logo smudged. For the "assemble pen" standards, see the attached QUALITY STANDARDS form. "Standard Sample" refers to the inspection method used (and described below).

Sampling. Bates Manufacturing will accept nothing less than a 99.5% quality index from its employees. This means that one bad pen in a box of 144 exceeds the limit (143/144 = 99.3%). Obviously, the company cannot afford to check every pen--so a sampling strategy is employed.

The quality inspector checks a box by picking, at random, 10 pens. If all are acceptable, the box is passed (and the inspector inserts an "Inspect By #__" ticket into the box). If one pen is found mishandled, another group of ten is checked. If none of the second group are defective, the original pen is returned to the operator for repair and the box is then passed. If another pen is found defective in the second group (or more than one of the first 10 is bad) then the operator must stop and, while on the clock, inspect the entire box--returning the finished box to the inspector for verification when completed.

Records are kept and any operator failing to meet the 99.5% level for a week is placed on probation for the following week. Being on probation means that the operator may not earn more than base rate for production time (on the theory that slowing down may increase quality). Failure to meet the standard during this week will result in disciplinary action ranging from continued probation to suspension to demotion to dismissal (depending on past history).

The inspection schedule is as follows:

Level 1: (includes all employees with less than one months service and all employees on probation)	20% check (i.e., every fifth box)
Level 2: (includes employees meeting the quality standards for the previous week)	10% check (i.e., every tenth box)
Level 3: (includes any employee with a 100% rating for the previous week)	5% check (i.e., every twentieth box)

Establishing the workplace layout

What does the workbench look like? Are machines required? Can you use existing equipment or must you buy/build new apparatus? For this job you will need, at a minimum, a worktable with trays to hold the component parts and a place to accumulate the finished product. Like the other components of describing a job, the layout cannot be done in isolation--you must have a method in mind (but not necessarily in detail) when you begin developing the workspace. Usually several trials involving various arrangements of materials and correspondingly different methods are required until the most efficient combination is found.

The attached diagram (JOB LAYOUT form) describes the workplace for assembling the pen. Note that the Stock #'s refer to standard tables, boxes, etc. used by Bates Manufacturing and kept in the warehouse. In this instance the supply boxes are not attached to the table to allow for individual differences (e.g., a six-foot operator versus one five- foot-two).

Department layouts. Templets are often used in developing plant or department layouts. These are typically cardboard or plastic scale models of standard tables, chairs, bins, racks, and other items found in a manufacturing operation. The accompanying drawing (on graph paper) was produced by outlining the templets and adding other details. It would be given to the maintenance staff as a plan for installing the equipment.

Standard outlines are usually made of each department or location within a plant. In some situations you will see a metal board on a manager's or engineer's wall with an outline of the facility drawn. Magnetic templets of machines, tables, etc. are then arranged to determine the layout for different products. Layouts are usually changed when the product mix changes.

Establishing the method

There are a few things to remember when developing a method. First among these is **don't waste effort**; i.e., have everything placed conveniently so that no wasted motions result from long reaches, operators do not have to search for things, and movement is kept as simple as possible. Remember, use both hands (and feet too, if possible)--do not let the left hand be idle while the right hand does something.

The question is not simply "Who can do it the fastest?" but "Under the same conditions and at the same pace, which method can be performed in the least time by a trained, average operator?" A high school basketball coach does not establish the method for shooting lay-ups based on Michael Jordan's technique--not many of us can dunk the ball from the free-throw line. Experience, trial-and-error, and, perhaps most importantly, the advice of experienced operators on similar jobs are your best resources for developing a new method.

The "assemble pen" method (see JOB DESCRIPTION) developed for this product is as follows:

The four component parts (case, refill, end, and cap) and the boxes for the finished pens are placed in receptacles on the workbench for the operator. The job sequence begins with the operator forming the box bottom (a collapsible cardboard type like a gift box that comes flat and must be "popped" up). From the receptacles on the workbench, the operator periodically grasps a handful of each of the components and places them on the table in a semi-circular arrangement.

The actual assembly involves picking up the case with the right hand while simultaneously picking up the refill with the left--inserting the refill into the case. Holding the pen with the right hand, the end (the small "plug") is picked up with the left hand and inserted into the case. Next, holding the pen in the left hand, pick up and attach the cap with the right hand. While placing the pen in the box bottom with the left hand, activate the counter with the right hand then restart the cycle until the counter reads 144 (if you are simulating this operation you may have to pretend you have a counter).

When the counter does reach 144, there are other things to do. The box lid must be assembled (in the same manner as the bottom) and attached, a ticket must be applied to identify the operator (it is collected by the person at the end of the conveyer belt and turned in for pay purposes), the finished box must be pushed onto a conveyer belt, and the counter must be reset to zero.

Establishing the time allowed

We have determined the most effective layout and method, how parts and supplies will be handled, what quality standards must be met, and how we will account for the number of pens assembled by the operator. Now we are ready to determine how much it will cost to assemble a pen-- and how many people are needed to staff the operation. Get out your stopwatch and clipboard.

Using a stopwatch. Several types of stopwatches are used to record times. One of the more common models is the decimal-minute snapback watch (see picture). This watch records time in hundredths of a minute; the slide mechanism on the side of the case starts and stops the watch, while pressing the crown resets the watch to zero. Using this watch requires reading the time almost instantaneously as you quickly "snap" the crown to restart the timing of the next element. This allows every element to be continuously recorded with no time out for recording or restarting the watch.

It is unlikely you will have a decimal minute or a snapback stopwatch to work with. More likely, you will have access to a standard "coach's" watch--i.e., a watch that measures in seconds and successive "clicks" of the crown start, stop, and reset the watch. These are sometimes used (usually in decimal minute or hour styles) by time-study technicians in a three-watch arrangement. In this configuration (see picture) three watches are attached to a common activator bar. "Clicking" the bar stops one watch, starts the second, and resets the third. Thus, at any given time, you are looking at one watch stopped on the latest recorded time, one watch is recording the present element, and one watch is set at zero--obviously, it takes practice to see all of this and record it accurately.

Assuming you have one of these "coach's" watches, try the following method of recording times:

First, attach a blank TIME AND MOTION STUDY form to a clipboard and cradle it in your left arm (reverse if you are left handed) while holding the stopwatch in your left hand. This provides a place to record your observations while leaving your right hand free for writing.

Next, complete the information at the top of the form, then begin timing the operation. You must determine clear, repeatable points to start and stop the watch (e.g., have a friend deal a deck of playing cards--start the watch when the first card hits the table, stop when the 52nd card does the same). Record your time on the sheet next to the description of the operation you are timing.

For your first few attempts, try timing several (e.g., 5) repetitions of an operation--say, dealing 10 rounds of four playing cards each. This will give you an average time per round (total/ 5) or per card (total/20). Next, try to record each round (then each card). Add the "auxiliary" times necessary for card-dealing to your study (i.e., shuffling the deck).

Timing Assemble Pen. Assemble pen has been broken down into four distinct components which are to be timed separately. You might try a different breakdown or even timing the whole operation (or even several repetitions) as one component. The more experience you gain in timing, the more able you will be to break a job into small parts; this will help you identify subtle movements in the operation and maybe eliminate wasteful motion.

Note that some times on the TIME AND MOTION STUDY sheet are circled. This is done to mark a time you measured but do not want to count in the total--for example, if the operator stopped to talk to you or dropped a part and spent excess time looking for it.

Remember that frequency is important--you pick up the pen parts once for every pen but the boxing is done only once per 144 pens. The number of times per box spent taking a handful of parts from the bin and placing them on the table depends on the number of the various parts in a "handful." Each time you record an occurrence of picking up a handful of parts, record the number of parts collected (this may be difficult in the case of, for example, ends where 100 or more pieces may be picked up at a time. In these cases, have the operator pick up several

handfuls while not performing the operation and find an average quantity to use in your calculations.

In the example (see TIME AND MOTION STUDY) the above technique was used to develop the times used to place parts on the table (quantities are recorded on the study sheet) and the times used to handle the boxing (10 repetitions of making boxes would have otherwise required watching 1440 pens being assembled). The times are then transferred to the JOB DESCRIPTION form where all times are reported "per box" (i.e., per 144 pens) since the operator will be paid for each box completed. Unfinished boxes at the end of a day will be left for completion the next day.

Rating the elements. If the operator you time to set the standard is working at 100% then everything is fine. However, if you time a very fast operator, then average operators will not be able to complete as many units (and will not make enough money, quit, and leave you holding the bag). On the other hand, if you time an extremely slow operator, you will pay too much for the operation, throw the earnings on this job
out of line with other operations throughout the plant, and your boss will find another time-study person.

Since you cannot always find a 100% operator, the alternative is to "rate" the operator you use to establish the time allowed. For example, an operator may take 10 seconds to finish one assembly. You estimate this operator is working at 80% efficiency so you allow 10 x .80 = 8.0 seconds for the assembly (i.e., an operator working at 100% would take 8 seconds to complete the job). If you had judged the operator to be working at 120% efficiency then you would allow 10 x 1.20 = 12.0 seconds for the job.

There are two keys to becoming an accurate "rater"--benchmarks and practice in cooperation with other raters. Benchmarks are standards agreed upon by the profession. For example, a person dealing a standard deck of 52 cards into four stacks in 30 seconds (under certain quality and methods criteria) is said to be working at 100%. Similarly, a person who walks unencumbered (without carrying anything) for a distance of 52.8 feet in 12 seconds (3 miles per hour) is at 100%. Appendices A and B describe these benchmarks more fully.

Benchmarks provide a start but since most operations involve more complicated movements than dealing cards or walking a straight line, practice in the real world of the production line is needed. Typically, a new time-study person is assigned to an experienced rater for training. Trainees typically practice rating operators on various jobs, comparing their ratings with each other and/or with the experienced rater. Experienced time-study technicians will, even on complicated operations, be within 5% of each other in their ratings.

Other costs to be considered

Those supervisors, parts people, packers, and quality checkers (not to mention your valuable services as engineer, the manager, payroll clerks, salespersons, etc.) do not come free--or even cheap. Allowances must be accounted for, unemployment insurance and rent paid, social security is mandatory.

Fortunately, there is an accounting department to figure such costs. Material costs are calculated separately from labor (operators' pay) and overhead (rent, taxes, administrative costs, etc.). Assume for this example that the material cost (pens, boxes) is $0.0225 per pen (i.e., 2 1/4

cents each). Other cost figures are often given not in terms of dollar amounts but as percentages of direct labor (i.e., piece rate) costs.

For our operation, accounting has provided the following percentages to cover expenses:

Indirect Labor (supervisors, quality checkers, allowances, etc.)	35%
Plant Overhead (Plant manager, secretaries, rent, taxes, utilities, etc.)	120%
Administrative Overhead (Corporate offices, salesmen, engineers, etc.)	80%

These figures are based on past experiences over a range of products for this particular plant. The attached PROJECTED PRODUCT COST sheet shows the calculations for the pen.

Putting it all together

Now we have a time for Assemble Pen. Using the appropriate base rate, the money paid for the operation can now be determined. The base rate for this operation is $3.60/hour or 6 cents per minute (see Appendix C); so completing a box of pens means the operator earns $1.98 (33.07 minutes x $0.06/minute) for that box (or approximately $0.01375 --one and three-eighths cents per pen).

Total cost (see PROJECTED PRODUCT COST) is $9.87 per box, approximately 7 cents per pen. This figure allows the merchandising department to determine the selling price (probably around $20.00 per box). Translated into terms the operator is most interested, each box completed pays the operator approximately $1.98--100% efficiency requires completion of about 14 1/2 boxes per 8 hours.

Remember, we have to be ready to produce 200,000 pens per week. At 33.07 minutes per 144 pens, this converts to approximately 1,389 boxes per week or 766 hours (45,931 minutes)--19 operators working at 100% efficiency for a 40 hour week. To allow for absenteeism, training time, lost time (what if some parts do not arrive on time), and other unforeseen disasters, we will probably need to hire 20 people.

Twenty people will require a full time supervisor and a full time quality checker (we can time this operation, too) and at least one parts supplier/packer (again, we can time--or estimate--the requirements for this job.

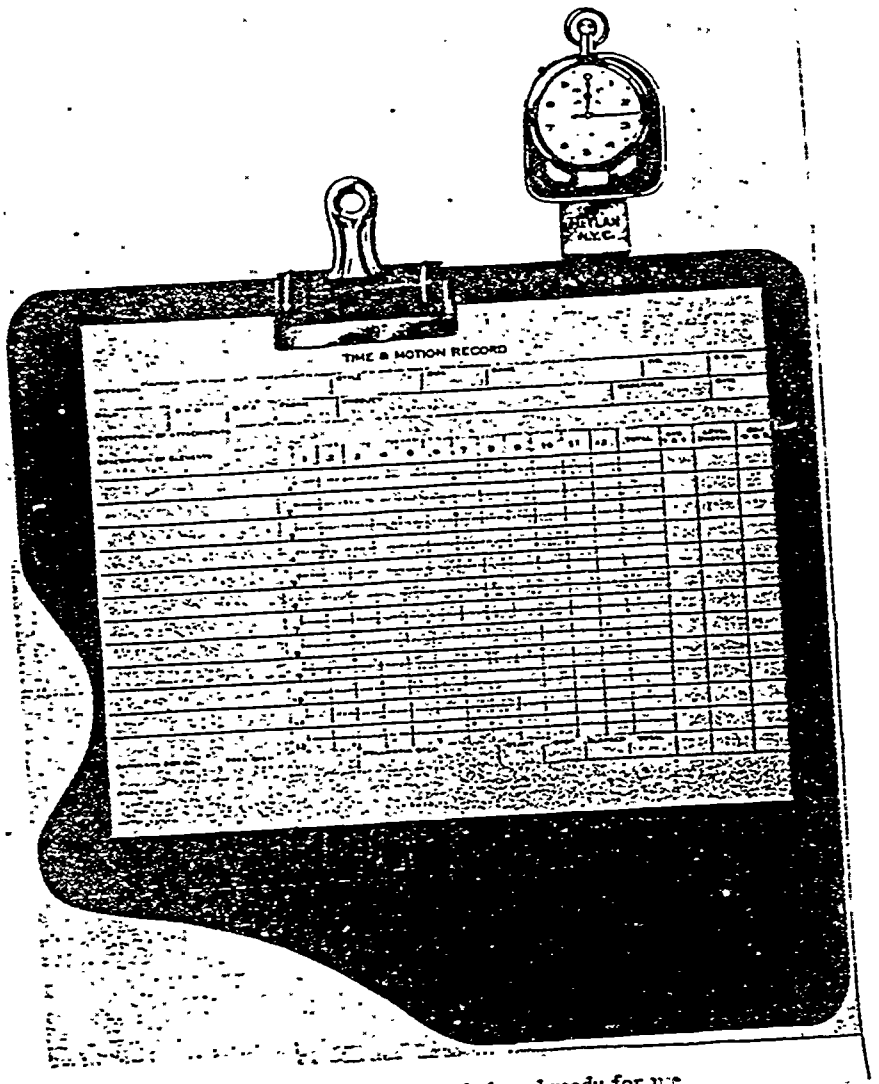
Finally, if we are paying out approximately $9212 per week ($0.04606 per pen x 200,000 pens), we can probably afford a fairly sophisticated machine to do the job. To be certain, it would be necessary to determine the savings brought by the machine versus the cost of the equipment and maintenance expenses. Suppose a machine that would produce 250,000 pens per week (with one operator) costs $125,000. Would you recommend purchasing one?

Other Uses

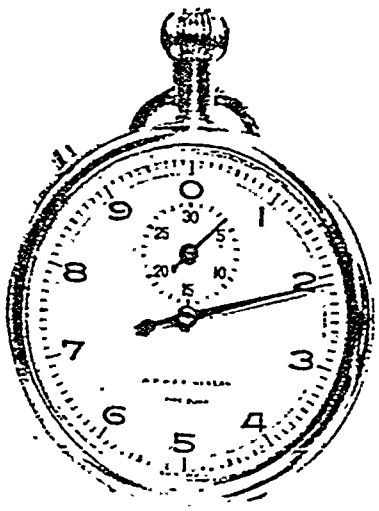
Even when employees are not paid on piece rate, time and motion study can be an effective tool. McDonalds, for example, is known as one of the most efficient of the fast food chains. This is in no small part due to the extensive use of time and motion study techniques to determine the necessary staffing loads and most efficient methods for making hamburgers. You may see, in a McDonalds, a manager walking around with a clipboard and stopwatch; this is part of an evaluation/follow-up procedure designed by the Industrial Engineers who conducted the studies to determine methods and manpower needs.

The same techniques have been used for determining office workers' schedules, methods, and seating arrangements. One primary use of time and motion study, alluded to above, is in "equipment justification." At what point (quantity of production) should automated equipment be purchased to replace manual operations? When should more modern equipment be purchased to replace older, less efficient machines?

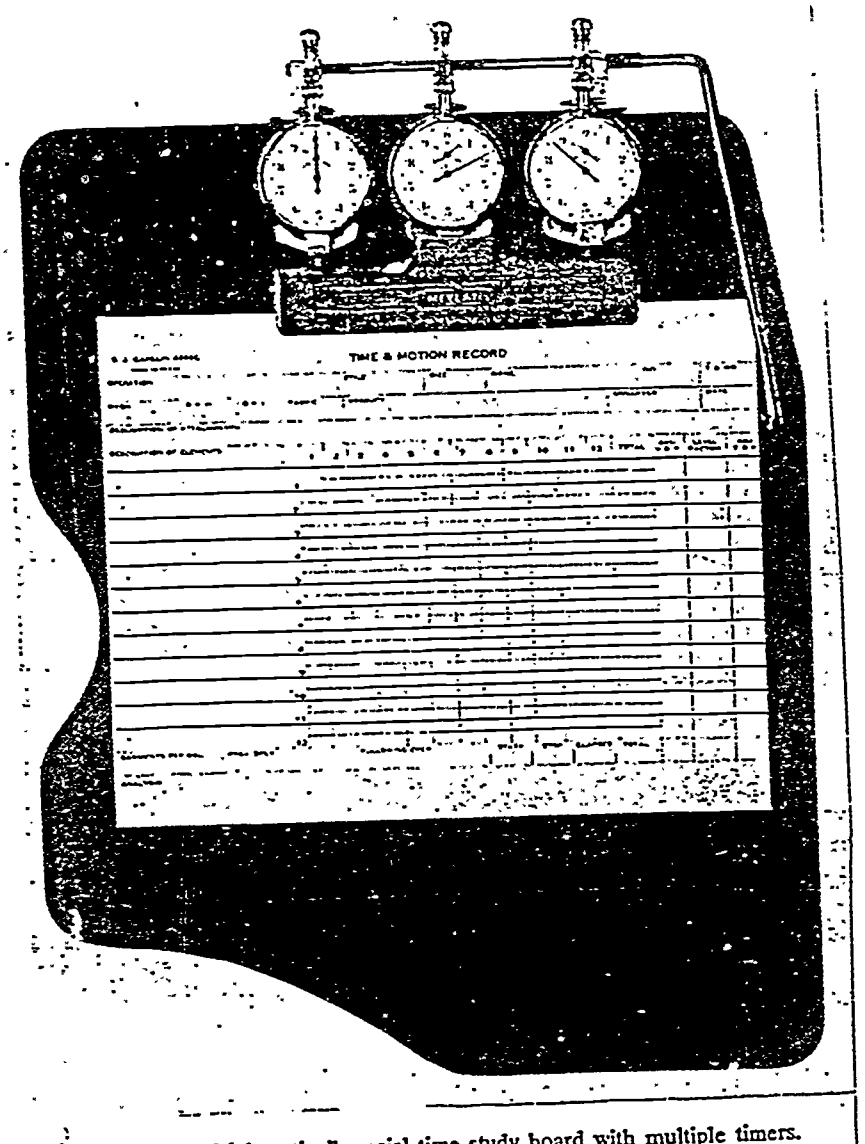
Stopwatches



Single time study board ready for use.



Decimal minute "snapback" stop watch.



"Triple action" special time study board with multiple timers.

Worksheets for "Assemble Pen"

BATES MANUFACTURING COMPANY
TIME AND MOTION STUDY

Operation: Assemble Pen | Style: 14C | Size: N/A
Name | Oper.# | Mach.: N/A | RPM: N/A
Product: Logo Pen | Observer: A. Timer | Date: 4/10/88
Attachments: None

	ELEMENT DESCRIPTION	1	2	3	4	5	6	7	8	9	10	TOT	AVG	RTE	ADJ	
A.	Get and assemble box bottoms	6	5	6	6	8	6	6	7	5	6	61	6.1	90	5.5	/box
1.	Get case w/left hand	4/4	5/3	3/4	3/4	4/4	4/3	5/3	5/3	4/4	(6)/3	72	4.0	90	3.6	/per
	Refill w/right - Assemble	—	—	—	—	—	—	—	—	—	—	—				
2.	Get and w/left hand,	3/4	2/3	3/3	4/2	3/2	3/3	3/4	2/3	3/3	4/3	60	3.0	95	2.9	
	attach	—	—	—	—	—	—	—	—	—	—	—				/per
3.	Get cap w/right hand,	3/3	3/3	3/3	3/3	2/3	4/3	4/4	2/4	3/2	3/3	61	3.05	95	2.8	
	attach	—	—	—	—	—	—	—	—	—	—	—				/per
4.	Place in box w/left hand,	4/4	5/5	5/4	4/4	3/5	6/4	5/4	4/5	6/4	5/3	89	4.45	85	3.8	
	activate counter w/right	—	—	—	—	—	—	—	—	—	—	—				/per
B.	Lid box, push to line, Apply tkt,	10	11	11	11	10	9	12	10	10	11	105	10.5	95	10.0	
	zero counter	—	—	—	—	—	—	—	—	—	—	—				/box
C.	Place handful of cases to table	4	5	4	4	4	Avg	Qty	=	13	—	21	4.2	100	4.2	/13 PEN
D.	Place handful of refills to table	4	4	5	4	5	Avg	Qty	=	38	—	22	4.4	100	4.4	/38 PEN
E.	Place handful of ends to table	3	3	5	5	4	Avg	Qty	=	160	—	20	4.0	100	4.0	/160 PEN
F.	Place handful of caps to table	4	5	3	4	4	Avg	Qty	=	45	—	20	4.0	100	4.0	/45 PEN
		—	—	—	—	—	—	—	—	—	—	—				
		—	—	—	—	—	—	—	—	—	—	—				

Start | Stop | Elapsed | Total

Units/Bdl: 144 | Previous Operation: N/A | Next Operation: N/A

Comments

BATES MANUFACTURING COMPANY
QUALITY STANDARDS

Operation Assemble Pen	Style 14C		Size N/A
Spec.# 311	Department C	Mach. N/A	RPM N/A
Product Logo Pen	Authorized By [signature]		Date 4/18/88
Attachments None			

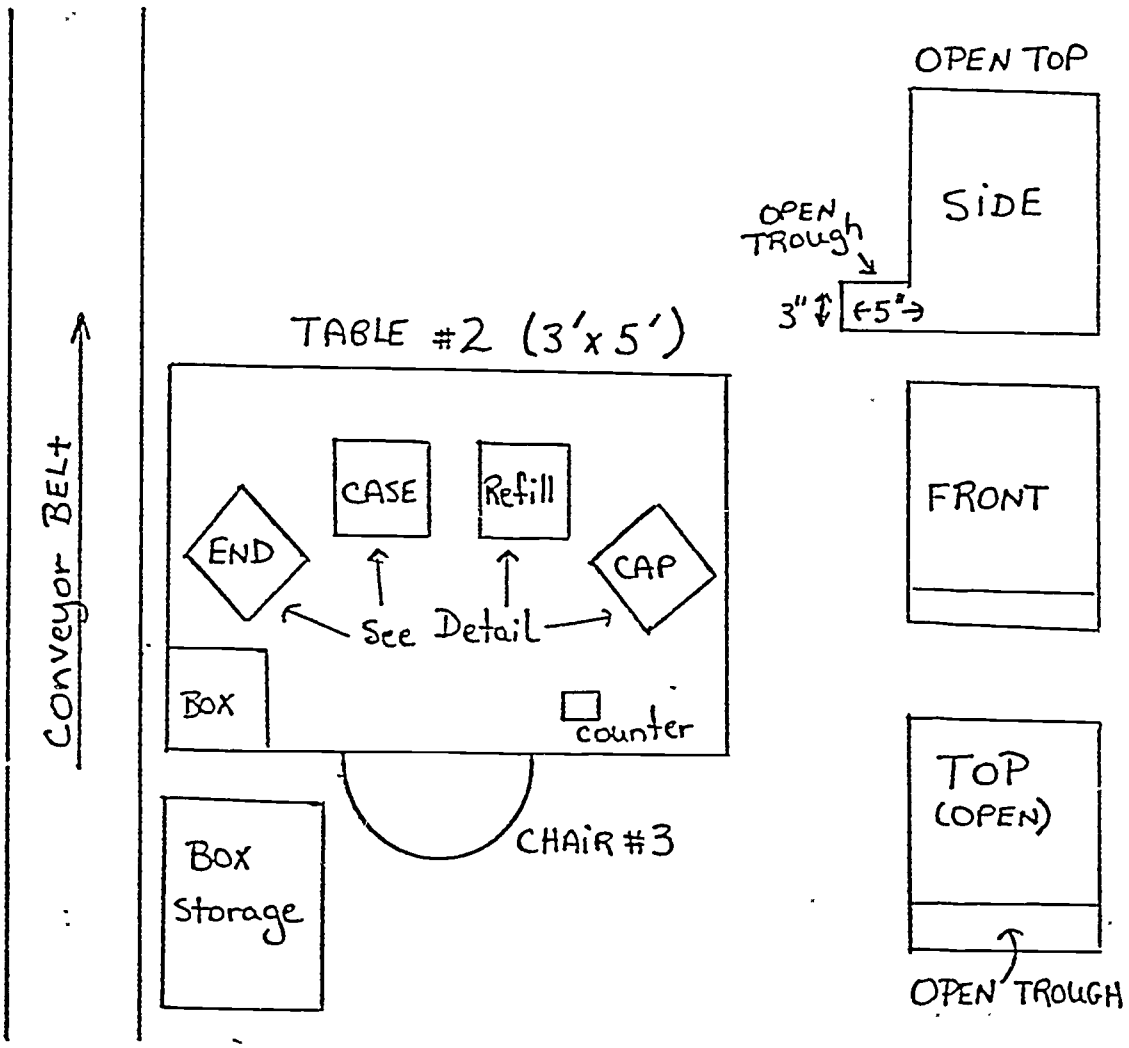
1. Printed Logo must be clearly legible.
2. Refill must be full.
3. End, refill, cap must be fully secured.
4. Clip part of cap must not cover logo.

Standard Sample

Units/Bdl 144	Previous Operation N/A	Next Operation N/A	
Comments			

BATES MANUFACTURING COMPANY
JOB LAYOUT

Operation Assemble Pen	Style 14C		Size N/A
Spec.# 311	Department C	Mach. N/A	RPM N/A
Product Logo Pen	Authorized By		Date 4/18/88
Attachments None			



Units/Bdl 144	Previous Operation N/A		Next Operation N/A

Comments

BATES MANUFACTURING COMPANY
JOB DESCRIPTION

Operation: Assemble Pen | Style: 14C | Size: N/A

Spec.#: 36 | Department: C | Mach.: N/A | R'M: N/A

Product: Logo Pen | Authorized By: JEO | Date: 4/18/88

Attachments: None

ACTION	Time	Frequency	Pay
Get and assemble box bottom	5.5	1/box	5.5
Get case with left hand, refill with right - assemble	3.6	144/box	518.4
Get end with left hand - attach	2.9	144/box	417.6
Get cap with right hand - attach	2.8	144/box	403.2
Place in box with left hand, activate counter with right	3.8	144/box	547.2
Lid box, push to line, apply tkt., reset counter	10.0	1/box	10.0
Place handful of cases to table (13)	4.2	11.1/box	49.3
Place handful of refills to table (38)	4.4	3.8/box	16.7
Place handful of ends to table (160)	4.0	0.9/box	3.6
Place handful of caps to table (45)	4.0	3.2/box	12.8
		Total	1984.3
		= 33.07 min/box	

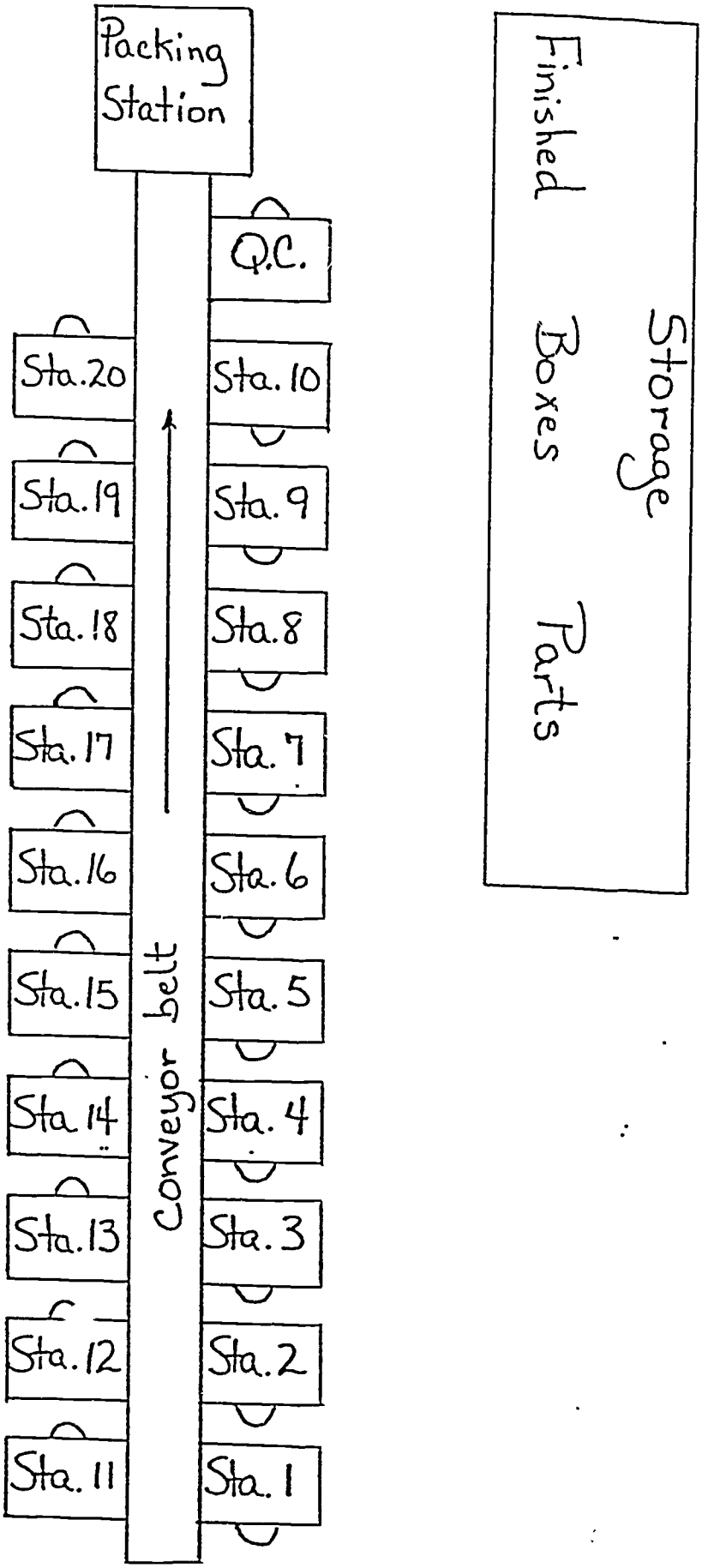
Units/Edl: 144 | Previous Operation: N/A | Next Operation: N/A

Comments: Base Rate - B

BATES MANUFACTURING COMPANY
PROJECTED PRODUCT COST

Product Logo Pen	Style 14C	Size N/A	
File # 837-A	Location Central	Auth. By JEO	Date 4/18/88

Direct Labor	$0.01375
Indirect Labor (35%)	0.00481
Plant Overhead (120%)	0.01650
Admin. Overhead (80%)	0.01100
Labor	$0.04606
Parts	0.02250
Total	$0.06856/per
	= $9.87/box


Packing Station
Q.C.
Sta.20
Sta.10
Sta.19
Sta.9
Sta.18
Sta.8
Sta.17
Sta.7
Sta.16
Sta.6
Sta.15
Sta.5
Sta.14
Sta.4
Sta.13
Sta.3
Sta.12
Sta.2
Sta.11
Sta.1
Conveyor belt
Storage
Finished Boxes
Parts

Exercises and Projects

Exercises

1) You start work at Acme Widget at 7:00 but there is no work on your regular job (base rate is $5.00/hour, your production average is $6.20/hour). At 7:15 your supervisor asks you to help out on another job which normally pays $3.80/dozen units. At 8:30 you return to your regular job after completing one dozen of these units. At 3:00 (with an hour for lunch) you have completed 36 units of product A ($6.30/dozen), and 42 units of product B ($6.00/dozen). From 3:00 to 4:00 you work on another job even though there is work available on your regular assignment, completing 18 units at a rate of $2.40/dozen.

   a) How much do you get paid for today?
   b) What is your production average for today?
   c) Your production earnings are what percent of your total earnings?
   d) What is your efficiency rating for your job?
   e) What percentage of your total earnings came from piece rate earnings (on your job and from your temporary assignment). If this level falls below 90-95% on a regular basis, the manager might be advised to consider another line of employment.

2) Your company's competition, in order to undercut prices, has the following allowance policy: Wait time is paid at minimum, other work at base if there is work on your job and at minimum if not. In order to lure employees, however, the competition advertises a base rate of $5.00 (i.e., multiply each piece rate by 5.00/4.80). How much less will you earn at the competitor's plant while doing the amount of work described in Exercise 1?

3) As a quality control director, you are charged with identifying operators who fail to meet the established quality standards. Your plant has 240 operators. On average, 10% are new employees, 15% are on probation at any given time and 10% have perfect quality rating for the previous week. If all operators were employed assembling pens and averaged 20 boxes per day, how many pens would you check (assume 15% fail the first check and must be re-checked)? If it takes 2 minutes to check a box, how many quality checkers does the plant need?

4) Design (draw to scale) a workbench and show how you would arrange the parts on the bench to:

   a) Fold one-page notices to be sent to each parent in your school, insert the notices in business-sized envelopes, stamp, and place in a box.
   b) Assemble a skateboard from its component parts.

5) You are charged with finding the most efficient layout for your classroom--i.e., the arrangement of desks, board, etc. that minimizes the distance the teacher must walk to visit each student and maximizes the student view of the board and the space available for materials (books, computers, overhead projector). Make a scale drawing of the classroom and cardboard templets of all equipment in the room. Try several arrangements and discuss the pros and cons of each. Rearrange your room (with the teacher's permission) to fit the best layout.

6) Determine the efficiency rating for the following:

a) a football player who runs 40 yards in 4.35 seconds;
b) a card shark who can deal seven cards to each of four people in 8 seconds;
c) an olympic track star who runs the 100 meters in 9.0 seconds;
d) a dragster running the 1/4 mile in 6.0 seconds;
e) a four-year old who deals ten cards to each of five people in two minutes twelve seconds.

7) The following operations, allowed times, and base rates are used to pay for assembling a picture frame.

Operation	Time	Base Rate
Assemble frame	2.04 minutes/frame	$4.12/hour
Insert glass	.08 " "	$3.86/hour
Insert picture & back	.42 " "	$3.60/hour
Box	.12 " "	$3.60/hour

Overhead costs include:		Parts costs include:	
Indirect Labor	85%	Frame	$2.85
Plant Overhead	92%	Glass	.24
Administrative Overhead	112%	Picture	.015
		Back	.13
		Box	.21

Determine the projected cost for one dozen of the product.

Projects

1) The marketing department just called--they changed their minds. Instead of a BIC-type pen they want a click-type. You now have to contend with five parts: the barrel, the refill, the top (with clicker inserted by the manufacturer), the small chrome ring that separates the top and bottom, and the spring. Re-do the example provided for this pen.

2) Joe's Shoes, your biggest customer, is tired of its salesmen having to lace shoes in the showroom. They want to know how much more you will charge them to lace the shoes at the factory before boxing. Determine the cost, quality standards, layout, etc. for both low-top and high-top tennis shoes.

3) For a money-making project for your club you have decided to make and sell wooden replicas of your mascot (using the woodworking shop). Ask the shop teacher to cooperate in simulating (or setting up) an assembly line to produce, paint, and package the replicas.

Appendices

Appendix A: Benchmark for Hand Movement

The basic standard (100% efficiency) requires one to deal a regular deck of 52 playing cards into four equal stacks in 30 seconds. Before you start dealing, however, there are two items to be considered: method and quality.

The method is the "normal" way of dealing cards. If you are right handed, hold the deck in your left palm (which is facing up). Slide the top card off the deck with your left thumb as you grasp it with the thumb (on top) and fingers (on bottom) of your right hand--the index finger of your right hand usually does not get involved. Left handers reverse the hands.

You should be sitting in a normal desk chair at a table or desk of standard height. The cards should be dealt into four stacks forming a diamond (a square turned on its side) with the stacks approximately 12 inches apart.

Quality standards **must** be observed. The resulting stacks should have each card overlapping the previous card with the entire pile fitting into a circle of diameter 9 inches.

Calculate the actual efficiency as $\frac{30}{\text{time (in seconds)}} \times 100$.

If you are using a decimal stopwatch then divide 50 by the number of one-hundredths of a minute taken, multiplying the result by 100 to convert to percent.

Note that there are alternative ways to deal a deck of cards--for example, the "two-handed" deal. In this variation, while the right hand is dealing the card in a normal manner the left thumb slides off a second card into another stack. The effect is like dealing two cards at once. The problem with this method is two-fold. First, this is not the method against which the standard is set--so, dealing 52 cards in 30 seconds using this method does not signify 100% efficiency.

Second, not everyone can do this. Try it, it takes quite a bit of coordination. If you were trying to design a "card dealing" operation you might want to train your dealers in this manner--it really is faster but quality tends to suffer. However, you might note that professional dealers (in Las Vegas casinos) do not use this method. This is primarily due to the fact that the gamblers would look with suspicion on someone who seems to be throwing out two cards at once (from who knows what end of the deck).

You should practice rating different people dealing cards until you are consistently within 5% of the measured rate.

Appendix B: Benchmark for Walking

The basic standard (100% efficiency) requires one to walk unencumbered for a distance of 52.8 feet in 12 seconds. This converts to 4.4 ft./sec. or 3 miles per hour. To calculate the actual rate at which a person is walking, mark off 52.8 feet on the floor then time the person walking across the marked block. To determine efficiency, calculate $\frac{12}{\text{time (in seconds)}} \times 100$. For a decimal stopwatch, divide 20 by the number of hundredths of a minute taken, then multiply by 100.

Remember to apply the same quality and method restrictions as with the hand-movements. The walk must be "normal" (no skipping or jumping) and along a straight, clear path with no load being carried.

As with the hand movements, practice until you consistently come within 5% of the measured rate over a range of times.

Appendix C: Setting a Base Rate

Systems for determining base rates vary considerably from company to company. Some are informal "guestimates," others very structured systems based on long experience. New employees are often assigned to a job based on tests of manual dexterity, intelligence, coordination, and/or stamina--higher scores being placed on jobs with higher base rates. The system described below assigns a point value to each of five criteria. The resulting rate scale is as follows.

Rate	Point Total	Base Rate
A	0 - 10	$3.35
B	11 - 20	$3.60
C	21 - 30	$4.00
D	31 - 40	$4.40
E	41 - 50	$4.80
F	51 - 60	$5.20
G	61 or more	$5.60

To see the effect of different base rates, consider two jobs each requiring 20 minutes to complete 100 units at 100%, one paid at a base rate of $3.35 and the other at a base rate of $5.60. An operator finishing 2400 units per day at the lower rate earns $ 26.80 per day while an operator at the higher rate earns $ 44.80 per day for producing the same number of units of work--a difference of $90 per week.

Criteria for Determining Base Rate

1) How long does it take an average operator to achieve 100% efficiency? An operation with a long "learning curve" suggests a considerable investment on the part of the company in the training of an operator. Paying a higher base rate offers the operator more incentive to remain on the job, saving the company the cost of retraining on a difficult-to-learn job.

less than 1 week	0 points
1 week to 2 weeks	5 points
2 weeks to 1 month	10 points
1 month to 2 months	15 points
2 months to 4 months	20 points
4 months to 6 months	25 points
more than 6 months	30 points

2) How fatiguing is the job? A job that requires considerable exertion will cause the operator to lose productivity as the day wears on. The fatigue factor may be calculated based on the estimated length of time a normal person can continue on the job without rest (e.g., indefinitely for non-fatiguing jobs to less than one hour for extremely fatiguing).

non-fatiguing	0 points
mildly fatiguing	5 points

moderately fatiguing	10 points
extremely fatiguing	15 points

3) How hazardous is the job? A dangerous job (what are the chances of a set right sprocket operator setting the right sprocket on her left hand?) requires more concentration. An injured operator, in addition to personal suffering, exposes the company to lost production and higher insurance rates--not to mention a possible visit from the Occupational Health and Safety Agency.

non-dangerous	0 points
mildly dangerous	5 points
moderately dangerous	10 points
extremely dangerous	15 points

4) How critical is the job? What if you get a little streak in the paint on the inside of a car door? or, if you cut the material for the pocket lining on a pair of pants a little crooked? Will the customer notice? Will a subsequent operation (e.g., sewing the pocket lining) be seriously affected? This is one way to pay for quality.

non-critical	0 points
mildly critical	5 points
moderately critical	10 points
extremely critical	15 points

5) What is the potential for loss? A diamond cutter and a rock splitter do the same operation in the same way. Which would you pay more? Can any damage be covered up or is a slip of the hand going to ruin a $500 product?

non-serious	0 points
mildly serious	5 points
moderately serious	10 points
extremely serious	15 points

Appendix D: Bates Manufacturing Co. Forms

Form #2360-08 Piece Rate Calculation

Form #2360-10 Quality Standards

Form #2306-12 Job Layout

Form #2306-14 Job Description

Form #3218-02 Projected Product Cost

BATES MANUFACTURING COMPANY
TIME AND MOTION STUDY

Operation | Style | Size

Name | Oper.# | Mach. | RPM

Product | Observer | Date

Attachments

ELEMENT DESCRIPTION	1	2	3	4	5	6	7	8	9	10	TOT	AVG	RTE	ADJ
	—	—	—	—	—	—	—	—	—	—	—			
	—	—	—	—	—	—	—	—	—	—	—			
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	—	—	—	—	—	—	—	—	—	—	—			
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	—	—	—	—	—	—	—	—	—	—	—			
	—	—	—	—	—	—	—	—	—	—	—			
Start	Stop	Elapsed			Total									

Units/Bdl | Previous Operation | Next Operation

Comments

BATES MANUFACTURING COMPANY
QUALITY STANDARDS

Operation	Style		Size
Spec.#	Department	Mach.	RPM
Product	Authorized By		Date
Attachments			

Units/Bdl	Previous Operation	Next Operation
Comments		

BATES MANUFACTURING COMPANY
JOB LAYOUT

Operation	Style		Size
Spec.#	Department	Mach.	RPM
Product	Authorized By		Date
Attachments			

Units/Bdl	Previous Operation	Next Operation
Comments		

BATES MANUFACTURING COMPANY
JOB DESCRIPTION

Operation	Style		Size
Spec.#	Department	Mach.	RPM
Product	Authorized By		Date
Attachments			

Units/Bdl	Previous Operation	Next Operation
Comments		

BATES MANUFACTURING COMPANY
PROJECTED PRODUCT COST

Product	Style	Size	
File #	Location	Auth. By	Date