

The Effects of Imposed Learning Curves on Performance Improvements

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Abstract: The results of a recent empirical study aimed at investigating the interacting effects of imposed goals, expressed by a dictated learning pace, and the individual's manual performance are presented. The results reveal that such imposition has an adverse effect when the imposed learning pace is slightly faster than the unpaced learning rate, and has no effect when the imposed pace seems to be too difficult. However, subjects can outperform their learning (progress) curves if they are motivated to do so by other techniques such as an amplified incentive scheme. Several industrial implications derived from this study are discussed.

■ An organization has a significant impact on an individual's motivation to improve his performance through the use of techniques such as goal setting, incentive systems and method improvement. The notion of performance improvement, which is a dynamic one, is typically depicted by a learning curve. Therefore, it is expected that an increase in an individual's motivation will show itself through a change in his learning curve. This study investigates the dynamic relationship between motivational techniques such as goal setting and incentive systems, and performance improvement as depicted by learning curves. The following section reviews some of the basic notions and findings in goal setting, incentive systems, and learning curves; followed by the study's hypotheses, a description of the study and analysis of the results.

The behavioral nature of individual performance investigated in the study, falls within the domain of the expectancy and goal setting models, with emphasis on goal setting. The expectancy model (Vroom [19]) is a process oriented model that explains the individual level of motivation through the chain of efforts, output, and reward. The individual develops expectancies with regard to the relationship between effort and output and output and rewards. To the extent that either of these expectancies decrease, it negatively affects individual motivation to improve performance.

Goal setting is a process intended to improve performance by specifying the desired outcomes toward which individuals and organizations should work. According to Locke et al. [9], a goal is what an individual is trying to accomplish. Other concepts similar in meaning include: performance standard, quota, and work norm.

Goals should be moderately challenging. If they are too easy to attain, the employee will approach the goal lackadaisically. If they are too difficult, the employee may not try to meet them.

Dimensions of goal content that have been studied are clarity and difficulty, with goal difficulty, referred to also as task difficulty, being the domain of this study. In their intensive literature survey Locke et al. [9] identified 110 studies dealing with the relation between goal difficulty and task performance, out of which 90% found that specific hard goals produced better performance than medium, easy, do-your-best, or no goals. Most of the studies investigated static goal setting, that is, the goals were not upgraded during the study. However, an organization may wish to initiate mechanisms that motivate its employees to seek continuous improvement. For that reason companies strive to adopt a dynamic approach of standard setting (Hirschman [7]; Turban [8]). Standard, in this context, is defined as a satisfactory level of performance. The dynamic approach expresses the standard as a rate of *expected improvement* rather than establishing a *static* performance level.

The philosophy that a company should continually improve

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its performance is clearly conveyed to all employees by adopting dynamic standards. Since yesterday's performance is not accepted as a satisfactory level for tomorrow's performance, it motivates employees and management alike to continuously look for ways to improve it. The basic idea behind the use of the dynamic approach in standard setting is the "learning curve" that relates performance of a specific task to the number of repetitions of that task. Performance can be measured by using various criteria such as cost per repetition and percentage of defects.

A few mathematical models have been devised to describe the relationship between the number of repetitions and performance. The models differ from each other by the formula used to depict the relationship. A comprehensive review of these models can be found in Yelle [22]. The most common model still in use is the one proposed by Wright [20, 21] who was also the first to formulate a mathematical model for the organizational learning curve. Since this model is relatively simple to explain and is at least as accurate as other common models (see Globerson [6]), it was used for this study. The model, also called the power model, has the following form:

$$T(s) = T(1)s^{-m} \quad (1)$$

where:

s = number of repetitions (units) since the start ($s \geq 1$)

$T(s)$ = performance time (man hours of the s -th repetition)

$T(1)$ = performance time for the first repetition

m = parameter of reduction ($m \geq 0$). It is a measure of the progress rate.

For each doubling of the cumulative production, the model yields a constant portion of reduction in performance time. That is, $s_2 = 2s_1$,

$$SL = \frac{T(s_2)}{T(s_1)} = \frac{T(2s_1)}{T(s_1)} = 2^{-m} \quad (2)$$

where SL is the portion of reduction, or the slope of the curve. The logarithmic transformation of the model is:

$$\log T(s) = \log T(1) - m \log s \quad (3)$$

which is the equation of a straight line with slope ($-m$). Linear regression is used to compute m from the logarithmic transformation of empirical data sets describing $T(s)$ as a function of s . Using the same data set, Figure 1 displays a learning curve plotted on a linear scale and Figure 2 a plot of the same data set on a logarithmic scale.

In Wright's study [20], m received the value of .32 when the curve was fitted to a set of data points describing the rela-

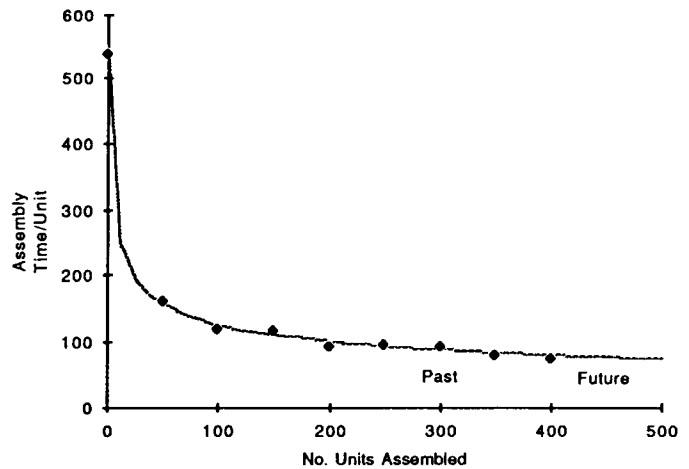


Figure 1. Fitting a power learning curve on a linear scale.

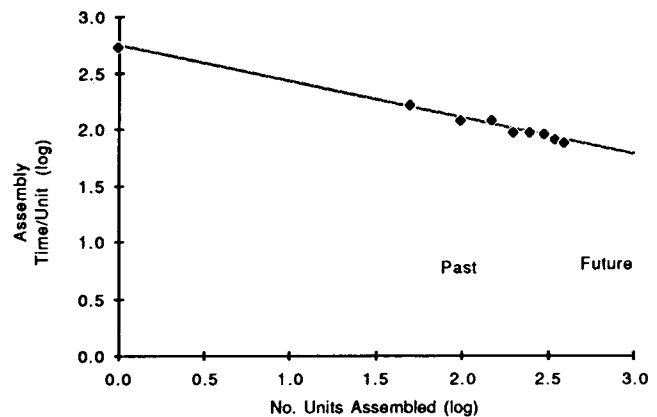


Figure 2. Fitting a power learning curve on a logarithmic scale

tionships between the number of airplanes assembled and the required direct labor. Substituting $m = .32$ into (2) gives $SL = .80$. That is, the direct labor required for the $2n$ th airplane is only 80% of the direct labor required for the n th airplane. The learning curve with a slope of 80 percent was identified from then on as a standard curve and is commonly called the "80 percent learning curve."

There is evidence, however, that the slope may receive different values depending on the product or the process involved. A study by Baloff [1] showed that in the production of some musical instruments the slope was around 88 percent, while for apparel items it was 78 percent. It is important to emphasize that the greater the slope, the smaller the expected improvement through repetitions; as the slope denotes the portion of time "left over" for future repetitions. There is also evidence that the level of automation has an impact on the learning curve. For example, Hirschman [7] shows that a greater improvement may be expected in labor intensive processes.

Empirical studies (e.g., Globerson [6]) demonstrated that the learning curve slope is different among individuals performing the same task. The deviations are largely determined by individual differences in physiological and mental abilities

to introduce improvement to their work. Improvements are manifested through the introduction of elements such as changes in work methods and facility layout. Laboratory experiments carried out by Gershoni [5] showed that improvement in the performance of an operation follows a learning curve only when subjects were paid according to an incentive scheme. Learning curves of subjects who were not covered by an incentive scheme leveled off shortly after the start.

Since improvement of organizational performance is highly related to the learning ability of individual members, it is important to investigate additional ways through which learning curves can be further improved. For example, a steeper improvement pace can be generated through imposition of work pace. Such an approach is expected to have impact not only on the individual's performance but also on his stress level. Stress is a consequence of a general response to an action or situation that places special physical and/or psychological demands on a person. Stress involves the interaction of a person and that person's environment (Quick & Quick [12]). An optimum level of stress probably exists for maximum performance of any task; too little or too much stress may result in lowered performance. Smith [14] lists factors affecting occupational stress: physical work environment, job involvement, organizational support, and workload. Therefore, imposing a work pace on workers with the objective of expediting their learning is expected to have an impact on their stress. A study by Stammer & Wilkes [16] confirmed this, but found that the stress level is of a *U* shape; high stress level for either a too high or too low workload. Work can be either self-paced or machine-paced. From Salvendy [13], review of machine-paced and self-paced work, it was concluded that each of them has advantages and disadvantages. However, Salvendy's study, as others, did not relate to a dynamic situation where workload increases with time to depict learning curves.

Objectives of the Study

The general objective of this study is to investigate the behavioral pattern of individuals who are exposed to dynamic goal setting, depicted by a learning curve, when performing a typical industrial task. The following are the specific hypotheses to be investigated:

1. It is possible to impose a steeper learning pace in order to improve an individual's learning pace, thereby generating a learning slope steeper than the normal one. The term "natural learning slope" refers to the improvement rate resulting from the performance of a motivated self-paced individual.

As stated earlier, a positive correlation exists between task difficulty and task performance. However, we are interested in finding if this conclusion holds true if the task difficulty is increasing, following a typical learning curve.

2. The imposition of a learning slope has an impact on the individual's stress; the steeper the imposed slope, the greater the individual's stress. The intention of this hypothesis is to identify the "stress strategy" used by individuals who are exposed to dynamic and difficult goals.
3. As imposed (or paced) learning slope increases an individual's performance deviation. The term "performance deviation" refers to the difference between the learning curve obtained by a regression line and the actual performance. This hypothesis and the next one are derived from the notion that imposed learning increases individual's stress resulting in less stable performance.
4. An imposed learning slope has a negative impact on the quality of output. This hypothesis is derived from the common belief that pressing employees to increase output has a negative impact on the quality of that output.
5. The "natural learning slope" can be further improved through the amplification of motivation. Money is known to be a powerful motivator of performance. Locke et al. [8] found that individual monetary incentives increased performance by a median of 30%. A study by Fein [4] of more than 400 companies found that the introduction of an incentive system boosted organizational performance by approximately 43%. The basic issue investigated in this hypothesis is whether an individual is able to improve his performance beyond the level achieved when using a conventional incentive system, such as the piecework.
6. Method improvement guidelines have an additional impact on the learning curve slope. Utilizing the maximum individual motivation to improve performance, a practical question to be explored is by how much, if at all, performance can be further improved using formal method improvement techniques initiated by the organization.

Design of the Study

A laboratory study was designed to investigate the hypotheses outlined above. The experiment consisted of assembling eighty electric outlets that were fed to each subject by a conveyor. Each assembly session lasted 3-6 hours, depending on the imposed learning curve slope. The feeding rate was controlled by the experimenter; he changed the time interval between every two items so that it would follow a desired learning curve pattern. For example, if an 80% learning curve ($m = 0.32$) is desired with a first cycle time of 1.25 minutes, then the second item would be fed by the conveyor after 1.25 minutes, the third item after 1.00 minute and so on, where the time intervals are calculated by (1). If a subject was unable to complete the assembly of an item by the time another item had reached him, the item on the

conveyor passed the work station and dropped into a box of uncompleted items. The recorded time for each unit was the net time required by the subject to assemble the item, rather than the time allowed by the conveyor. That is, if the conveyor allowed 0.95 minutes but the assembly was completed within 0.87 minutes, then 0.87 was recorded by the experimenter.

Sixty five subjects participated in the study. All were university students hired for this study. A short description about the study was posted, asking for male subjects to contact the coordinator. Due to budget limitations and an inability to investigate many variables, it was decided to control for subject sex and include only males in this study. Admittance was granted for the first sixty five subjects who filled out the application. Their age was within the range of 21 to 32 years old. The subjects were randomly assigned into six groups with the first consisting of fifteen subjects and ten subjects in each of the other five groups. The reason for assigning fifteen subjects to group 1 as compared to ten subjects for the other groups is explained later. All subjects received an hourly salary as well as a piecewise bonus. The bonus was based on the number of completed items during the work session, as well as on their quality. Four quality levels were established:

Level one — an item was completed according to specification

Level two — a minor defect, such as an untight screw

Level three — a medium defect, such as a loose screw

Level four — a severe defect, such as a missing part.

Quality of items was determined by the experimenter who checked each item after it was placed, by the subject, in the box of completed items. There were no operational problems to identify that an item belonged in level one or four. However the discriminability between level two and three was not as clear and the validity of this measure is in doubt. However this was not of great concern since very few cases fell within the middle two categories.

The following quality weights were assigned to the levels; 1.00, 0.75, 0.50, 0.25. For example, if a part was missing in the assembly (level four), the subject would be credited with just 0.25 items.

Table 1 summarizes the experimental conditions for each group.

The study was performed in two stages with a partial analysis in between to allow the identification of the baseline condition for the second stage. Results of groups 1 and 2 fed the learning curve parameters for groups 3 and 4. Groups 5 and 6 were also designed in the first stage.

Group 1 was used to identify the two parameters $T(1)$ and SL (or its equivalent m) for the natural learning curve through a regression analysis. This group consisted of fifteen sub-

Table 1. Description of the Experimental Conditions and Objectives of the Six Groups

Group Number	Condition	Objective
1.	Self-paced learning (no conveyor)	Identify parameters of "natural" learning curve and establish study range
2.	Imposed learning with an 80% slope	
3.	Imposed learning with an 86% slope	Investigate the impact of the imposed slope value, on individual's performance
4.	Imposed learning with a 92% slope	
5.	Self-paced learning with amplified incentive	Investigate the ability of additional performance improvement
6.	Self-paced learning with amplified incentive and method improvement guidelines	Evaluate the impact of further performance improvements

jects in order to obtain more reliable estimates of these parameters. Identification of these parameters allowed the establishment of the value of the imposed slopes for groups 2, 3, and 4.

Subjects belonging to group 1 picked up an item from a nearby box, completed it, and then started with the next one. Work pace was not imposed on them. They were, however, motivated to work fast since they were paid a lump sum after completing the assembly of all the items regardless of the time required.

Items for subjects in groups 2, 3, and 4 were fed by a conveyor with a pace that followed selected learning curve slopes (80%, 86%, 92%). The selection process of the slopes followed two stages:

1. Identification of the average slope of the "natural learning curve" (group 1). The average slope was found to be around 95%.
2. Selection of 80% as the first imposed slope (group 2), since it is a common slope. Analysis of subjects' performance with an 80% imposed learning curve revealed that they were able to complete 40 items out of the eighty which they were fed (50 percent completion). Therefore, it was decided that 80% is an extreme slope for this task and can be used as the lowest boundary. Then the two-points of 86% and 92% were selected to cover the range, keeping in mind that the smaller the slope, the heavier the demand on subjects.

Having the slope of 92%, which is slightly below the natural slope, enables us to study the effect of assigning dynamic goals that can be considered of moderate difficulty. Selecting 86% as a mid slope between 92% and 80% provides an intermediate slope aimed to support the investigation regarding the relationship between the imposed slope and performance.

The stress level generated by each of the working conditions was evaluated through an analysis of a stress questionnaire devised and validated by Spillberger et al. [15]. Subjects were asked to fill out the questionnaire after they had completed the work session.

Results and Analysis

The analysis of the results was based on subject performance as depicted by individual learning curves, quality of work, and stress level.

The end result of a work session with each subject was a completed stress questionnaire and a data set. The data set specified the time assigned to complete each unit, the actual time taken by the subject to complete that item, and the item's quality. If an item passed by the work station and was not touched by the subject then nothing was marked in that time. Table 2 demonstrates a partial data set.

item no: (s)	1	2	3	4	5	6	80
assigned time:	1.48	1.18	1.04	0.95	0.88	0.83	0.36
actual time:	1.35	1.25	1.25	-	1.18	1.17	0.95
quality index:	1.00	1.00	.25		1.00	1.00	.50

Having a data set for each subject made it possible to calculate the following:

1. The learning curve parameters based on the actual time required to perform the task. The parameters were found by fitting a regression line to the data of each subject.
2. An evaluation of the quality of the subjects' output on the basis of the ratio of equivalent items properly completed to total items completed.

The objective of the first set of experiments with subjects in (group 1) was to identify the parameters of the natural learning curve, $T(1)$ and SL . Both parameters received a wide

range of results. The values of $T(1)$ and SL that were used for the imposed learning curves were based on the values obtained for the natural learning curve.

Selection of the average $T(1)$ as the representative values would mean that only 50% of the subjects would be able to complete their task within this time. It was decided to select a value of $T(1)$ large enough so that it could be easily attained and subjects would start with the impression that the task was not a difficult one. Therefore, it was decided to select a $T(1)$ value in which 90% of the subjects were able to complete the first item. The selected value was $T(1) = 1.48$ minutes (an average of 1.33 and standard deviation of 0.18). The average slope was $SL = 94.9\%$, a surprisingly high value since the frequently cited value is 80%. Further literature investigation revealed that most of the studies dealt with organization learning curves rather than individual ones (Yelle [22]). Organizational learning curves are steeper than individual ones because of the organizational ability to impact areas such as planning and technological improvements, on which an individual does not have any impact.

A learning curve was established for each subject based on the performance data gathered during the experiment. The observed learning curve slope (SL) was the parameter used for further analysis. Table 3 presents the results obtained from the regression analysis of the six groups.

The "Assigned Slope" column specifies the imposed slope. "Actual Slope" is the average slope of the individuals participating in the group, with the "Standard Deviation" presented in the next column. The root of the mean square error estimates about the regression is given by " $S^{1/2}$ ". "MAD" stands for Mean Absolute Deviation. It measures the observed dispersion between the actual and predicted task times. "Percent of Defects" specifies the "equivalent" percent of units that were improperly assembled. "Stress Index" is the average Spilberger's stress score calculated for each group. The standard deviation of the stress index is presented in the next column. The multiple correlation coefficient R^2 estimates the proportion of total variation explained by the actual model. (Some researchers prefer adjusting it ($Adj-R^2$) for the sample size and the number of slope parameters.) The relatively high values of the R^2 of the groups on which no learning pace was imposed may serve as evidence for the validity of the power equation, for modeling self-paced learning. Finally, the significance of the regression models is given by the F statistic.

Gr. No.	Assigned Slope	Actual Slope	Std. Dev. of Slopes	$S^{1/2}$	MAD Abs. Dev.	% of Def.	Stress Index	Std. Dev. of Stress	R^2	Adj- R^2	F	$Pr(>F)$
1	-	94.9	2.0	.51	0.125	0.00	27.5	5.6	.837	.814	219.56	.0001
2	80	95.6	1.7	.20	0.135	0.75	29.5	4.6	.553	.547	4.33	.0407
3	86	95.4	3.5	.24	0.115	0.40	28.1	4.5	.625	.621	130.02	.0001
4	92	97.8	2.4	.07	0.185	0.66	34.7	5.5	.656	.651	148.73	.0001
5	-	92.6	3.1	.41	0.341	0.00	29.7	4.9	.756	.753	242.25	.0001
6	-	92.9	2.7	.38	0.295	0.00	29.8	4.7	.805	.802	6.204	.0149

These models seem to explain a major portion of the variance: from 74% (group 2) to 91% (group 1). The significance level of the F-test also proved satisfactory. Furthermore, recall that the primary research objective is not the development of new predictive models but rather evaluating the interacting effects of work pacing with the individuals' progress rates, outgoing quality, dispersion and occupational stress.

The following sections are devoted to the analysis of the hypotheses stated before:

1. Imposition of a steeper learning curve increases the individual's improvement rate. Statistical comparison between the slopes obtained by subjects in group 1 and the ones obtained by subjects in groups 2, 3 and 4 did not reveal significant performance improvements (one way analysis of variance). In other words, the results of this study do not support the hypothesis that the learning pace can be improved just by feeding work at pace faster than the natural one. The conclusion is even more extreme: in circumstances where the imposed learning slope is just slightly steeper than the natural one, the actual individual slope is less steep than the natural one. A comparison between the actual slopes of groups 1 and 4 reveals that the slope of group 4 is less steep (reflecting a slower learning rate) than that of group 1 ($P < 0.01$).
2. The imposition of a learning slope affects the individual's stress. Table 3 indicates some differences in the stress score associated with the first four groups. There is a significant difference in the stress score between group 1 and 4 ($P < 0.05$); the stress in group 4 is *higher* than in group 1. A possible interpretation of this finding is that as long as the imposed slope is significantly different from that of the natural one, subjects accept the imposed one as an unachievable objective and therefore do not try to reach it all. If the slope is perceived as being within their reach, they are motivated to follow it, which results in an increase in stress.
3. An imposed slope generates an increase in performance deviation: Comparison of the population deviation of group 1 to groups 2 and 3 did not reveal a significant difference (t test). A possible explanation for this phenomenon is related to the difference between the natural slope and the imposed one. If it is perceived by the subject as an extreme difference, the subject will not try to follow the imposed one and will stick to the natural slope, resulting in regular deviations. However, the deviations of groups 1 and 4 are significantly different ($P < 0.01$). That is, an imposed slope which is around the natural slope generates a higher deviation. The increase in deviation points to a possible relationship between stress and deviation; the higher the stress the larger the deviation.

4. An imposed learning slope has no impact on quality: 85 percent of the subjects did not produce any defective items, the other 15 percent (9 subjects) had less than one equivalent defective item each. None of the groups was found to have more defective items than the others. Therefore, one can conclude that subjects in this experiment were not willing to trade quantity for quality.
5. The natural learning slope can be further improved through the amplification of motivation. This hypothesis was investigated by introducing an additional motivational factor for group 5, as compared to group 1 where just a lump-sum incentive scheme was used. Following the completion of the first twenty items, subjects in group 5 were told that they would get an *additional* bonus based on the ratio of the time taken to complete the last twenty items divided by the time taken to complete the first twenty. By informing the subjects in group 5 about the additional incentive only after they completed the first 20 items, a reference point common to groups 5 and 1 was established. The ratio on which the additional incentive was paid was calculated by the following formula:

$$RATIO = \sum_{i=1}^{20} T(i) / \sum_{i=61}^{80} T(i). \quad (4)$$

The average ratio for group 1 was 0.83 and for group 5 was 0.76. This amounts to a further performance improvement of around 10% with regard to the time required to complete the last 20 items. The difference was found to be significant ($P < 0.05$). This result is intriguing; it suggests that the use of a multi-stage incentive system (that is, addition of another incentive system on top of the first one) has a positive impact on individuals' performance.

Performance improvement manifested itself also through the learning curve slope; a significant reduction from 94.9% to 92.6% ($P = 0.05$).

6. Method improvement guidelines have a significant impact on learning curve slope. A short method improvement training was introduced to group 6 after they had completed the first twenty items. As part of the training, subjects were briefed about basic concepts such as simultaneous motions, proper use of tools, and optimal station layout. Subjects of this group were also offered an additional bonus similar to the one offered to subjects in group 5. The average ratio of time required to complete the last 20 items, to the time required for the first 20 was further reduced to 0.70. The difference between group 6 and group 5 was significant (t test, $P = 0.11$); hence another improvement of around 10% is attainable when using some training in self-initiated improvement methodology. No significant difference was found between the learning curve slopes.

Summary and Conclusions

The majority of studies concerned with models of learning curves have been directed toward the empirical estimation of the parameters and the assessment of future performance. Reports indicating the impact of imposed learning curves on performance are scarce. In this laboratory controlled study both machine and self-pacing factors were considered with respect to their impact on the learning curve of a common industrial assembly task.

Statistical analysis of the results indicates that self-paced learning was superior to machine imposed learning. The use of steep slopes of machine pacing had a nominal effect on quality, stress and performance deviations within the individual's learning curve. On the other hand, machine pacing — slightly steeper than the natural learning pace — resulted in significantly increased stress and an inferior slope as compared to the natural one. This study suggests a persistent coping strategy; when a too difficult task is imposed on subjects who are motivated to perform, they regress to their normal performance level. When the imposed task is slightly more difficult than their normal ability subjects try unsuccessfully to cope with it, resulting in performance lower than normal. When self-paced subjects are given an additional bonus for improved performance, they are able to further improve their learning pace. Introducing a short training session in method improvement, although improving final performance, did not have an additional impact on the learning curve slope. This result may point to the value of the steepest learning slope which can be achieved by an individual.

These observations are consistent with a previous study by Morawski [10] who showed that self-paced inspection activity always leads to a higher value than externally paced inspection. Altogether, our results refute the arbitrary use of machine-paced job design strategies to improve the learning process of workers on assembly lines. However, the results of this study contradict the hypothesis suggested by Stedry and Kay [17] that small changes between required and actual performance do not significantly effect performance. It also contradicts Bassett's (1970) finding that goals expressed in shorter time limits led to a faster work pace than longer time limits. The contradiction raises an interesting research question, namely, what is the maximum difference between normal and imposed performance that will still not discourage people to follow the imposed pace?

The following are some practical implications derived from this study: a) It is better to motivate for improvement rather than dictating its pace. b) Employees do not tend to trade quality for quantity. c) Stress generates performance fluctuation. Therefore, if stable performance is desired stress should be kept low. d) Superimposing another incentive system on the top of an existing one brings further performance improvement. e) Training a motivated employee in method improvement techniques results in further performance improvement.

Further research should concentrate on two areas:

1. Dynamic goal setting around the natural pace. Investigating the impact of imposing goals around the "natural" preference, where the goals are slightly higher and slightly lower.
2. The relation between stress level and performance deviation. Is a higher stress level related to greater performance deviation?

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