STUDY OF WORK EFFICIENCY DURING OVERTIME PERIODS

by

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SUMMARY

This study was undertaken to obtain information relating to the effect of hours of work on work efficiency; more specifically it was desired to learn what efficiency could be expected of snowplow crews operating in overtime periods.

The study produced considerable evidence relating to hours of work and efficiency. However, because of the many direct and indirect factors inherently present in work situations (for example, the highly important motivational factor present in snow removal operations), no precise quantitative evaluation of expected efficiency was deemed advisable or possible.

The data reviewed did seem to indicate that even with considerable motivation, efficiency falls noticeably near the end of the second shift. Continued deterioration may be expected on through the night with a small recovery possible at daylight. Because of this, as well as the added safety hazards present on the highways during storms, it is recommended that the work period be limited to 16 hours except in extreme situations. Further, 2-hour plowing tours during period of falling snow seem to be advisable, with a chance given the crews to rest and relax either on the road or at the garage. Finally, if the work period extends much beyond 18 hours, it is recommended that a crew not be assigned work in the next 12 hours, and preferably it should be held off until the following day. This recommendation was made because the data indicated the likelihood of quite inefficient performance until the crew members are thoroughly rested.

INTRODUCTION

The objective of all supervisors ought to be the accomplishment of the work under their direction in the most efficient manner. The conventional definition of efficiency can be used here; that is, the ratio of output to input. Since in seeking truly efficient operations management must consider all factors which can affect the work, the input term must have a broad interpretation. It must not be limited solely to the immediate expenditure of energy, for example, but should evaluate the effects of accidents, fatigue, loss of health, boredom, loss of free or leisure time as well. This liberal concept of input might best be thought of as the total cost of work. All input factors, favorable or adverse, are reduced to a common denominator, the dollar, and summed algebraically. Thus, an efficient operation can be assumed to be an economic operation. It is only in this sense that efficiency can have a truly significant influence in the design of effective work situations.

In order to properly interpret experimental work relating to efficiency as it has been defined, certain concepts must be understood. The first of these is a worker's capacity for work. A person performing a task according to a specified method has at any given moment an upper limit to the speed at which he can perform the work. This varying limit is known as his capacity. Second, the factors which cause this limit to vary are known as governors and include temperature, light, noise, rest periods, sleep or lack of it, hours of work, methods, etc.

The rate at which the work is actually performed is subject to the motivation and incentive present. It is related to capacity by effort. The closer the actual pace approaches the capacity limit, the greater the effort. Hence, effort will change with either a change in the rate of work or in the capacity. If work methods or procedures change such that the capacity is raised, the rate of work can be increased correspondingly with no increase in effort.

It can be seen that effort includes energy expenditure as well as additional factors. Effort is preferred in this general approach since it is appropriate even when little or no energy is consumed.

An optimum effort level is reached at maximum efficiency. Generally, this level is somewhat below maximum effort because as the rate of work approaches the capacity limit, wasteful methods are apparently adopted by the worker. The greater effort does not give a proportional increase in output. Similarly, below the optimum the input cost per unit produced would not be favorable. The optimum level is relative, however, since demands and values change, e.g., emergencies, war, boom or depression times. What is really wanted is the minimum effort level which is consistent with the demands of the work situation as well as of the efficiency index.

Fatigue can be thought of as the reduced capacity for work or a governor. Thus, the onset of fatigue reduces the capacity limit and the rate of work decreases unless the motivation changes.

The function of fatigue appears to be that of a protection, a warning device to prevent exhaustion of muscles, nerve fibers or brain cells. However, rarely under modern work situations is muscle or cell exhaustion approached, yet no one will deny that fatigue is present. On the other hand, some remarkable recoveries are made merely at the suggestion of an evening of bowling or perhaps bridge. An explanation for this inconsistency is given by Maier (1) 1/ in terms of motivation. Apparently in addition to setting the effort level, the motivation experienced strongly influences the energy or resource allotment made to a particular task. This assignment is normally considerably below the total energy available yet fatigue begins to appear as it is utilized, signifying the approaching end of the energy supply. The subject feels truly fatigued, yet additional motivation at any time can bring forth resources from the reserve and he "comes to life." This is the source of the energy for the

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1/ Figures in parenthesis following the mention of publications refer to the list of references at the end of this report.

seemingly superhuman activities that have been accomplished under great emotional strain. These activities appear to be superhuman only because they are compared with normal allotments of resources and effort levels.

It is quite obvious from the foregoing that the total input cost can never be precisely measured. Some of the factors cannot be adequately expressed in cost units or any other units of measure. Others are so complex or are so interrelated with still other factors that the individual effect cannot be isolated except possibly in the laboratory. Yet, management would be stopping short of the goal if it failed to consider efficiency from this broad viewpoint. What it must do is appraise the factors it can in terms of dollars and then measure the balance indirectly, using subjective as well as objective means along with common sense. These are not the most satisfying conditions for a scientifically trained person yet no other alternative exists at present.

Ryan (2) has summarized the measures that are available. First, there are those which show promise of developing into valid indices of fatigue and other costs of work but which are still in the developmental stages. These tests include muscle potential, skin resistance as an indication of tension, steroid excretion, flicker fusion. The principal problem here is determining at what level will efficiency be affected significantly. Certainly, the results in themselves can suggest the possibility of the nature or extent of the influence and common sense can carry on from there. The second group of tests are those which are appropriate only for certain types of work. These include oxygen consumption and perhaps pulse and heart recovery time. The third group are cruder indices from a scientific point of view but they are easy to apply. Admittedly, they are stopgap in nature until better techniques are perfected. This last group includes output decrement curves, errors, variability and accidents during performance, long-term trends in productivity. It is obvious that these tests are subject to a host of variables (for example, any or all of the elements of the input) almost to the extent that the analyst may not know exactly what his data does show; yet, if properly interpreted, tests of this type provide helpful information as to the effect of certain factors on efficiency.

THE PROBLEM AND THE METHOD OF STUDY

In times of emergency certain activities may have to be continued or initiated after normal working hours. The opening of snow-clogged highways is one such situation. Maintenance supervisors must decide whether the intensity of the storm is great enough (and not too great) to continue or undertake plowing operations. If the decision is made to proceed, then the plows must be manned. Beyond this is the manning of work crews the following day for continued snow removal and routine assignments.

The question under consideration is how long is it advisable to keep men on duty without a period for normal rest. Analysts of the Iowa State Highway maintenance study group discovered that at times men would be on snowplow duty all night and then would continue on normal duty the following day, thus going close to 40 hours without a normal sleeping period.

Common sense immediately questions the advisability of such a long work period. However, before suggesting a policy change with regard to hours of work, the engineers assigned to the maintenance study group sought to discover what, if any, scientific data were available in the literature describing similar situations elsewhere and which might be of assistance to them in preparing possible recommendations.

This study, therefore, involves no original experimentation or data. Rather, a fairly extensive literature search was accomplished in an effort to gather together as much relevant material as possible. Then, the various aspects of the problem were considered in light of the findings.

LITERATURE REVIEW

The particular factors of work efficiency under surveillance are successive hours of work and the lack of sleep. An abundant supply of relevant articles and publications are available. Unfortunately, many have little original or additional information to offer.

The articles that are referred to below all appear to be fairly valid studies. They fall into four categories: general, industrial or production, automotive or truck, and aircraft - both military and civilian. For ease of presentation, only the more pertinent findings are summarized.

General

1. Classical ergograph studies on muscular activity produced among others the following results:

(a) Time for complete recovery increases rapidly as work period is increased (closer to complete exhaustion). Doubling the work period may quadruple the recovery time.

(b) Ability of muscles to do work is decreased by loss of sleep. (3)

2. Under special motivation, energy expenditure was shown to range from 14 percent to 68 percent greater than the control but less fatigue was apparent. This supports the contention that motivation increases amount of energy available. (4)

3. Evidence supporting energy distribution according to motivation presented in behavior of rats under normal and high motivation. (5)

4. Eyestrain produced easily by having subject in subdued light look at quickly flashing light. Rapid dilation and constriction of pupils is an example of muscular conflict which is quite fatiguing. No eyestrain appeared after 6 hours of continuous reading in normal light. (6)

5. Work which requires constant alertness or attention is subject to interference known as "blocking." In adding a column of numbers a person may be "stuck" at one sum and have to repeat it a number of times before the block is broken and he can proceed. Mistakes tend to occur at blocks. They are a few seconds in duration and may occur several times a minute. Continued work involving attention produces increases in the length and frequency of blocks. (7)

6. Seventeen subjects stayed awake without drugs for 100 hours. Psychomotor tests (muscular activity) showed very little change due to lack of sleep. Mental tests were performed with difficulty, however. (8)

7. Subject stayed awake 220 hours as part of disc jockey marathon. No significant behavioral effects observed in first three days. Likewise nothing significant could be measured in psychological and biochemical tests over this first period. However, deterioration was noted in all tests. Over the 9 days the subject had cyclic variation in performance experiencing irritability, paranoid thinking, visual hallucinations, episodic rage, deficits in thinking and visual-motor performance. (9)

8. A 5 mg. dosage of D-amphetamine (Dexadrine) effectively mitigated work decrement for a period of 7 hours. Test periods were 7 hours in length. (10)

Industrial or Production

1. (a) Production in afternoon shift shows effect of fatigue by being at a lower level than morning production, particularly in case of longer workdays. Ratios of afternoon to morning production for 7.5-hour day is 1.00; for 8.8-hour day, 1.0; for 10-hour day, 0.98; and for 12-hour day, 0.90. The "practice-efficiency" effect probably causes these ratios to be higher than they really are.

(b) Reduction of working hours per day and per week gave considerable production increase. For example, women working $74\frac{1}{2}$-hours per week and then shifted to $55\frac{1}{2}$-hours per week eventually increased average hourly output and exceeded total output of $74\frac{1}{2}$-hour week. However, men doing heavy work on a double shift (16 hours) once every 3 weeks maintained a production level only 4.7 percent below normal. Explanation given suggusted the motivational reserve plus the possibility of below normal vigor the next day or two. (11)

2. (a) Accident rates tended to increase with each successive hour work of the work period. Maximum rates may be 2 to 4 times greater than those experienced at start. Part of the increase was no doubt due to higher production rates but number of accidents increased disproportionately as output fell near end of work period. The effect was attributed to fatigue.

(b) Number of accidents experienced by women workers over a 12-hour day were 2.73 times greater than those experienced working a 10-hour day. Men who felt fatigue less had only 1.14 more accidents under similar conditions. (12)

3. (a) For light work performed beyond 8-hour day, 48-hour week, 3 hours were required to obtain 2 hours of output. For heavy work, 2 additional hours for 1 hour's output were needed. Five 10-hour days were not as effective as six 8-hour days.

(b) Injuries increased disproportionately as hours increased. One plant increased hours from 40 to 48 per week and got 50 percent increase in severity rate. Going from 48 to 60 hours nearly tripled frequency rate in another plant. (13)

4. Study of female employees in metal fabrication plant, light semi-skilled work, 40-hour week, hourly wages, showed the following:

(a) Production significantly higher in morning (decrease of 13 percent in afternoon).

(b) Lowest production in last hour of afternoon.

(c) Total delay time in afternoon greater by 50 percent over morning.

(d) Employees apparently influence in the non-working time to working time ratio rather adopt slower work methods when fatigued. (14)

Automotive

1. Studying the relationship between fatigue and hours of work in 900 truck drivers, U.S. Public Health Service analysts tested the drivers with regard to speed of tapping, reaction-coordination time, simple reaction time, manual steadiness, body sway, driving vigilance, and ability to distinguish flicker. Drivers who had not driven before the test had the highest efficiency, those who had driven under 10 hours had the next highest, and those who had driven over 10 hours had the lowest. Those who had been driving before the tests performed less efficiently with respect to aiming, resistance to glare, and speed of eye movements. No

significant difference was seen between the 1-10-hour men and those who had driven over 10 hours, however. (15)

2. (a) A 1935 survey indicated that less than normal sleep in past 24 to 48 hours was cause for most driver-asleep accidents. Five automobile drivers out of 8 having accidents had been without sleep for 16-20 hours and nearly 50 percent had less than 4 hours in last 24. Most common hour for driver-asleep accidents was 2 a.m.

(b) One in 3 driver-asleep accidents was a trucker-asleep accident. One-third had been driving from 4-8 hours since last sleep, one-third had been on the road 16 hours or more. Most common sleeping period was 2 to 3 hours. Eight in 10 lacked normal sleep in last 24 hours, 9 in 10 lacked normal sleep in last 48 hours. Most common hour for trucker-asleep accident was 5 a.m. (16)

3. Tests on drivers who drove about 300 miles every other day indicated the following:

(a) There is a demonstrable fatigue effect of long automobile drives on body reaction.

(b) Long automobile drives tend to decrease the fading time of vascular skin reaction; increases unsteadiness in standing; decreases the accuracy of hand-eye coordination; decreases visual efficiency; decreases the speed and accuracy of mental addition.

(c) The tendency of long automobile drives is to produce a loss of effectiveness and motor reactions similar to those required in driving. These observations suggest that the effect of a long automobile drive may render a driver temporarily prone to accidents. (17)

4. Based on experience of sport car drivers in France, recommendation is made for drivers to stop every 300 miles to exercise and to allow for 24 hours of rest before driving again if trips are of 650 miles or more. (18)

5. Use of drugs, caffein or the amphetamines (Benzedrine or Dexedrine) may be of assistance in combating fatigue or the tendency of drivers to go to sleep. Caffein is effective but is not as long lasting. The amphetamines could be safely used to prolong wakefulness at least 48 hours. (19)

Aircraft

1. In long duration flights a noticeable deterioration in a pilot's performance takes place. It was observable over a 40-minute interval and over the total 15-hour flight. More specifically:

(a) Errors in altitude and heading got progressively greater in second and third watches (fourth watch, the last showed slight improvement).

(b) Turbulence which tends to cause greater concentration than still air did not appear to cause pilots trouble until the third and fourth watches.

(c) Two-hour watches were recommended for pilots with opportunity to sleep and eat to minimize performance deterioration. (20)

2. Errors in performance of radio operators on 15-hour sortie, 5-hour watches were analyzed. Operators were on radio only one watch per sortie, changed radio watch each sortie, but did have duty assignments the full 15 hours.

(a) Decrement noted in performance over 5-hour watch.

(b) Performance dropped consistently from one watch to the next, the third roughly 20 percent poorer than the first.

(c) Twenty-four hours off duty between flights appeared to be sufficient to prevent fatigue accumulation. (21)

3. Subjective observations on Tokyo airlift confirm deterioration noted in 1 and 2 above. Irritability, sleepines, lack of tolerance. tension, loss of initiative and leadership ability all seemed to be present on long flights. (22)

4. The so-called Cambridge Cockpit Studies indicated the following:

(a) The fatigued pilot can see as small a difference in an instrument reading but he does not do anything about it until the difference is somewhat bigger than the deviation causing the rested pilot to act. After 2 hours ability to discriminate may not have changed but it may take 3 to 4 times as much deviation to cause corrective action to be taken. Pilot's concept of acceptable standards becomes lower as he becomes fatigued.

(b) Performance can be kept high if sufficient motivation is present. (23)

5. Review of CAB's report on Italian airliner crash on approaches to Idlewild in 1954 notes the Board believes fatigue was a factor in the crash. They cite the pilot's poor adherence to the localizer path, the last descent to a very low altitude before the sharp pull-up, and the evidence of abrupt control action. The crew was "on board" $22\frac{1}{2}$ hours prior to crash but it was large enough so that duties could be rotated and adequate sleeping facilities were available. The presence of fatigue is explained by the high mental and physical demands placed on the pilots by the four landing approaches over the $22\frac{1}{2}$ hours. Anxiety or worry was said to have similar effects as actual work accomplishment. The combination of anxiety over the flight and the actual strain apparently was not compensated by en route resting. (24)

Additional articles are believed pertinent to the subject matter but could not be obtained at the time of this study:

Civil Aeronautics Administration, "The Rate of Fatigue in Pilot Performance." CAA, Div. of Res. Report 61, Washington, May 1946

Davis, D. R., "Pilot Error." Some Laboratory Experiments, Air Ministry, A.P. 3139A, 1948.

Fraser, D. C. and Samuel, G. D., "Aircrew Fatigue in Long Range Maritime Reconnaissance, Effects on Vigilance." Air Ministry Rept, FPRC 907.10, 1956

McFarland, R.A., "Fatigue and Stress and Their Roles in Military Operations." O.R.O. Symposium, 1952.

McIntosh, B. B., et. al., "Pilot Performance During Extended Periods of Instrument Flight." USAF Tech. Rept., 6725, 1952

Reid, D. D., "Fluctuations in Navigator Performance During Operational Sorties." Air Ministry Air Pub., 3139, 321, 1947.

DISCUSSION

The condition of work being considered here is a very infrequent but quite long overtime period in which good motivation is present. The motivation factor is quite significant in the opinion of the writer since snow removal seems to be one of few work activities of highway maintenance personnel which really stimulates the entire crew. This may in part be due to the favorable recognition and publicity usually gained by the men as they clear the roads. It is quite easy to recognize the accomplishment and immediate worth of the service rendered by the crew's efforts. A sense of pride is attained here to an extent probably not matched in any other maintenance activity. In addition, if the activity takes place at night, one of few opportunities for additional pay is presented. In view of the prevailing wage structure, the opportunity for overtime pay is quite likely welcomed.

No studies were found which exactly duplicated the conditions described above. It would appear that the military would be interested in problems of this nature but many of the papers from that source examined for this study were concerned with the cumulative effects of a series of long duty periods. Because of the lack of data from essentially the same work conditions, the analysis must be based upon an extrapolation of evidence from what might be called cognate situations.

Much of the material reviewed and classified under the heading of General supports the contention that motivation influences the amount of energy made available to a certain task. This particular characteristic is quite important in the work situation under study because of the likelihood of fairly high motivation.

Of interest also in this group was the report on eyestrain caused by flashing light. It is quite possible that the flying snow produces strain of this type. This may be compounded somewhat, too, by snow flying up and back from the plow.

The evidence gathered on lack of sleep seems to be fairly uniform in showing little deterioration in muscular activity due solely to lack of sleep. Sleepiness or the distraction of fighting sleepiness appears to be of more importance to the problem at hand.

The Industrial or Production articles are helpful in two ways. First, it was reported that overtime, particularly without special motivation, is quite inefficient from a production point of view. It is quite true that the expected performance for a single overtime period (the situation under study) is likely to be greater than that obtained if the extra hours were worked every day. However, the decrement noted quite consistently over a normal shift was quite significant and it appears that considerable motivation would have to be present to overcome it. Of interest here is the effect of highly motivated second and third shift work on the output on succeeding days. Unfortunately, nothing but an assumption was available on the next day "vigor" of the men who loaded iron into a furnace for 16 hours straight every third Sunday. It is quite likely that the heavy added demand coming irregularly had considerable after effects.

Secondly, the relationships involving accidents are quite interesting. It is shown fairly well that accidents tend to increase with the speed of the operation. Thus, accident frequency rises as motivation and practice speed up the work. However, as fatigue slows the process down it also continues to make the employee even more susceptible to accidents. Finally, as length of working hours is increased, the chance of accidents goes up simply because of greater exposure. The cost of accidents and injuries is apparently a factor of considerable importance on the question of work efficiency.

Many of the articles reviewed under the Automotive heading refer to long mileage trips. It seems reasonable to assume that comparable results would have been observed had the subjects spent the same time going possibly at a much slower rate but under as much or more tension. If this assumption can be accepted, these data are quite pertinent to the present study. Also, in view of the possibility of the snowplow crews working all day and driving plows on into the night, the driver-asleep accident data seem particularly pertinent in appraising the length of the working period.

The conditions experienced by the aircraft crews probably come closest to those observed for the snowplow crews. Duties were rotated some providing for change of scene; the wakeful hours approached 24; fair motivation level present, particularly for the pilots; attention and alertness were required. It is interesting, then, to note the deterioration that takes place in performance in the later watches. In a few instances some improvement was noted in the last watch, it is true. This was explained as probably due to the arrival of daylight and the "end-spurt" frequently found when the end of a work period is approached.

The willingness of the aircrews to accept greater and greater deviations from normal operation as fatigue increases is also quite significant. It appears that a similar phenomenon existed in many of the work or performance studies reported under the Automotive and Industrial headings. Deterioration of output is not as critical in the present problem as is the tendency to relax normal safety precautions. It is quite possible that just such a relaxation is the major cause for the increase in the number of accidents experienced by fatigued or poorly motivated workers.

The failure of the study to uncover specific references to efficiency during irregular overtime periods is surprising as well as disturbing. The case of the men loading iron for 16 hours every third week stands alone in the study. However, it is believed that the provision for rest between flights makes the aircraft data reasonably descriptive of the situation under consideration in this study.

CONCLUSIONS

In view of the specific conditions believed present and the experience reviewed in this study, the following conclusions seem appropriate:

1. No quantitative estimate of work decrement can be made for maintenance employees involved in overtime snow removal operations. This is due in part to the difficulty of determining a satisfactory measure of work accomplishment but mostly due to the factor of motivation which is believed quite significant in this particular activity.
2. The efficiency experienced during overtime snowplow operations decreases with length of the work period but probably does not become a question for concern until after 16 consecutive hours of work. The decrease is due mainly to the increased likelihood of accidents but some work decrement may take place, particularly if motivation drops. The chances are very good that work decrement may become quite noticeable by the beginning of the third shift.
3. Removal of the special motivation factor associated with the plowing operation would cause the overtime operation to be quite inefficient. Saturday work during regular working hours would be preferred to night work on a normal work day.
4. Work periods longer than 24 hours would be extremely inefficient, particularly if the storm had abated and the employee was assigned to routine work.
5. Lack of sleep by itself probably has little effect on the ability to perform work. It may well be an important factor in the consideration of efficiency because of sleepiness and the distraction of fighting to stay awake.

RECOMMENDATIONS

1. Snow plow crews should be limited to 16 hours of continuous work. In an extreme situation this might be extended to 24 hours.

2. Operators should not be kept plowing continuously for longer than 2-hour periods. They should be allowed to rest either on the road or at the garage, encouraged to stretch or engage in some form of mild exercise, perhaps drink some coffee and eat some food. A warm meal should be considered if the work period extends beyond 16 hours.

3. If continuous plowing is required well into the night, alternate crews might be used to allow time for rest and relaxation.

4. For those men troubled with sleepiness, use of drugs such as caffein or the amphetamines might be considered.

5. Any man working much over 18 hours should be kept off the job for at least 12 hours or preferably held off until the following day. Any work performed by these individuals is likely to be highly inefficient until they are thoroughly rested.

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