An Industrial Engineer Looks at Highway Maintenance Operations

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The title of this paper would indicate that I am an outsider looking in on maintenance problems. However, I have been working with maintenance operations for nearly 20 years and have been working specifically with highway maintenance operations since 1962. The importance of making maintenance operations more efficient is well recognized. It is my purpose to indicate what industrial engineering has to offer to further the aim of making more effective use of our maintenace resources.

Industrial engineering became popular around the turn of the century when it became evident that industrial enterprises had grown so large that individuals could no longer control the enterprise. Since individuals could no longer control the enterprise, some system had to be created in order that information be readily available for decisions which must be made periodically for the enterprise to remain competitive. Thus, industrial engineering is a child of the capitalistic system. If there were no competition and if we were not worried about making the operation more efficient, there would be little use for industrial engineers. The text definition of industrial engineering is as follows: "Industrial engineering is concerned with the design, improvement, and installation of integrated systems of men, materials and equipment. It draws upon specialized knowledge and skill in the mathematical, physical and social sciences together with the principles and methods of engineering analyses and design to specify, predict, and evaluate the results to be obtained from such systems." I shall attempt to relate each of these facets to the highway maintenance problem.

Because of certain abuses in the principles of industrial engineering, the "efficiency expert" name was tacked on to early industrial engineering efforts and the resulting prejudices have carried over until today. Many older practicing engineers think of a stopwatch when industrial engineering is mentioned. The stopwatch to the industrial engineer is sort of synonymous with the transit to the civil engineer. The transit gains information for the civil engineer; the stopwatch gains information for the industrial engineer. Many civil engineers pursue their career with little or no contact with the transit. This is particularly so in the areas of soil mechanics, traffic, transportation, structures and the like. Similarly, many industrial engineers perform their day-to-day work without seeing or using a stopwatch. The stopwatch-efficiency expert idea of an industrial engineer is no more valid today than is the idea that mechanical engineers work mainly with steam engines or the accountant is the individual who sits on a high stool with a green shade penning figures into a ledger.

Many highway departments consider only civil engineers when seeking technical employees. Occasionally, a mechanical or electrical engineer is tolerated. This thinking fails to take into consideration the makeup of a modern curriculum in other engineering disciplines. The chemical engineer knows as much or more about the makeup of asphalt as does the civil engineer; the electrical engineer is certainly in a position to advise on the design of modern highway traffic control systems; the industrial engineer is in the position, where the optimum use of resources available to the highway department, can be realized.

WORK MEASUREMENT

Perhaps the area which most highway maintenance people are involved in at the present time is that of work measurement and work simplification. Up to a short time ago, maintenance jobs were performed by an all purpose crew who were sent out to the site, performed the necessary work, and returned to a central collecting point. Under this system management had advocated the responsibility of how a job was to be done to the craftsman himself. No attempt was made to inform the craftsmen of how the work should be done and how long the crew should be involved in their work. They merely returned when the job was finished. In addition to making a very inefficient system, this situation precluded any effective scheduling effort. Since the crews could not be adequately scheduled, efficient use could not be made of them. In addition to this, different crews did things in different ways, not always the best way. No data were available with which to justify additional mechanical equipment in terms of savings in man-hours.

Today, many states have embarked on programs to measure all or nearly all of the jobs that are done by maintenance crews. This measurement not only includes the number of hours required to do the job, but also includes the optimum number of craftsmen and equipment which should be available. In this way, the maintenance dispatcher can plan ahead for the groups to do more than one job in the future. Work measurement efforts as used today in highway work usually take two forms. The first is the stopwatch study and, in my opinion, this effort should be minimized since the length of time of most of the elements that we are trying to measure are much longer than those which require stopwatch studies. Whereas in the hard goods productive plant we are talking in terms of a hundredth of an hour, in highway maintenance operation if we could peg down our jobs to the nearest five minutes, we would be very happy. Because of this, the normal type of wristwatch can be used to try and create a set of standards for the work of the highway maintenance craftsmen. I have just mentioned the work "standards" for the first time. Standards is simply a word which includes the determination of how long a job should take and the use of that length of time in designing a maintenance system for future operations.

By far the best tool for the analyses of highway maintenance operations is the work sampling technique. Work sampling is a measurement technique for the quantitative analysis, in terms of time, of the activity of men, machines, or of any observable state or condition of operation. Work sampling is particularly useful in the analysis of non-repetitive or irregularly occurring activity, where no complete methods and frequency description are available. It is also an extremely useful device with which to make an inexpensive overall survey of office, shop, or service activity. Such a preliminary study can help evaluate the need for further study, and it may serve to establish a benchmark for managerial purposes because it is extremely convenient, possesses known reliability, and because it operates without recourse to the stopwatch or to subjective judgments of "effort" or "performance."

A work sampling study consists of a large number of observations taken at random intervals. In taking the observations, the state or condition of the object of study is noted, and this state is classified into predefined categories of activity pertinent to the particular work situation. From the proportions of observations in each category, inferences are drawn concerning the total work activity under study. As an example, if a group of maintenance men are observed to be "waiting" in a third of the observations made of their activity, we might draw the inference that better scheduling or supervision, rather than increased crew size, represents the most fruitful area for improvement

The underlying theory of work sampling is that the percentage of observations recording a man or machine as idle, working, or in any other condition reflects to a known degree of accuracy the average percentage of time actually spent in that state or condition. If observations are randomly distributed over a sufficiently long period of time, this theory is held to be true, regardless of the nature of the observed activity. Work sampling observations may be likened to a series of photographs taken at random times, with the added advantage that the observer is capable of on-the-spot interpretation and classification of what he sees.

Work sampling utilizes the well-established principle of drawing inferences and establishing frames of reference from a random sample of the whole. In this case the "whole" is the total activity of the area, persons, or machines observed during the entire period of time over which observations are made. Work sampling is a practical compromise between the extremes of purely subjective opinion and the "certainty" of continuous observation and detailed study. The advantage of work sampling is that the taking of a few random observations can be done economically, usually as a collateral duty of supervision, while other detailed methods of appraisal are more expensive and may require the full-time services of groups of specialists.

The exact degree of reliability required of any study is dependent upon the end use to which the study will be put.

An essential condition of work sampling is that observations be taken at random. Randomness in the statistical sampling sense means the condition that any given instant of time has an equal likelihood of selection as the time for observation as any other instant, that there is no apparent order to the times of observation, and thus, that one time of observation is independent of all other times of observation. Finally, the entire period of time over which samples are taken must be subject to selection as the random times of observation are drawn. If these conditions are met and enough observations are taken, inferences of known reliability may be made through work sampling. There are several straightforward tests by which the randomness of times of observation may be verified or tested. If careful attention is paid to these tests, the accuracy and reliability of work sampling studies can be developed to within any practical limit. By "practical" is meant the answer, dollarwise, to the question: "How much certainty of results is desired for the expense involved?"

STANDARDS

The logical step after work measurement is the creation of maintenance standards. Many states, for example, Minnesota, Virginia and Louisiana, are engaged in extensive standardization programs. It can readily be seen that maintenance cannot be adequately scheduled unless management has some idea of how long it should take to do a job. Conversely, the time taken to do a job cannot be ascertained unless the job is standardized, that is, unless the job is done in the same manner each time it is performed. The method study and motion technology aspects of industrial engineering help the engineer to design a method which requires the least effort. Once this method has been performed then the time taken to do the job can be ascertained and this used by the maintenance planner in his scheduling work. Additionally, this information can be used to ascertain the long-range manning requirements for any highway maintenance effort.

A modern aspect of the method analysis procedure lies in the area of value engineering. This is but a new name for an old idea. Value engineering identifies a specific system of decision-making which is aimed at the creation of a product or service with the highest possible value to the user at the least possible cost. Instead of looking at the cost production problem from the narrow view point of "how can we produce this service most economically?", a more comprehensive concept is taken by questioning "how can we produce the function that is required for the least total cost?" This is the philosophy underlying the value engineering approach. This approach has already effected the development of the new production and maintenance systems, and it will exert an even greater influence on methods and machines as it permeates the engineering maintenance and manufacturing field more widely. In highway maintenance work, an example of value engineering might be the consideration of the total grass cutting problem, not just how to cut grass better with mowers. The entire system from beginning to end would be formalized, that is written down, and consideration would be given not only to mowers but also to chemical treatment, elimination of grass and replacement with aggregates and any other ideas which in total would minimize the cost of roadside maintenance.

PERSONNEL RELATIONS

Necessary to any industrial engineering curriculum is one or more courses having to do with industrial and personnel relations. Typical of the topics covered in such courses are union and management collective bargaining, recruitment and selection, employee appraisal, promotion, transfer, lay-off and demotion, training, supervision, effective use of meetings, communication, discipline, wage and salary administration, and wage incentive programs. The applications of these topics to maintenance management is so clear that specific examples to the highway maintenance field are not required.

MAINTENANCE CONTROL

In preparing a student for the industrial engineering field, a course in production control is usually included in the curriculum. Some universities, particularly Louisiana State University, are lending greater emphasis to maintenance control than production control merely because most of their students go into work in a chemical or chemical-processing plant where maintenance control is a large factor. Nevertheless, the technology underlying the production and/or maintenance control field is common. The emphasis is on the word "control," whether it be maintenance or production.

Traditionally, these control procedures have included: (a) forecasting, (b) planning, (c) scheduling, and (d) follow-up. To these four traditional areas have been added network analysis known as critical paths scheduling and PERT. In addition, the use of the computer in performing these jobs is now emphasized with all the attendant problems.

The forecasting aspect of control encompasses the ascertaining of what resources will be needed by the maintenance supervisor for some foreseeable future. The resources, of course, are men, material and machines. The planning aspect is the methodology of how the resources will be put to best use. The scheduling function is the determination of when the resources will be used and the follow-up aspect is the feedback mechanism by which the maintenance manager ascertains how well the plan is keeping up to the schedule. The PERT and critical path analysis techniques are used to determine the longest job or endeavor in the maintenance system and the shifting of idle resources to this longest path function so as to cut down on the total time and cost required for the function.

ENGINEERING ECONOMY

Engineering economy differs from classical economy in that the engineer learns about the value of money rather than price theory. Most engineers do not receive the financial motive emphasis in their undergraduate curriculum. This concept permeates the entire industrial engineering curriculum in that the student is constantly made aware of the fact that the engineer is a person who can do with one dollar what any other damn fool can do with five dollars. The newer concepts of engineering, and this is particularly emphasized in industrial engineering, include the idea that a product or system should not merely just work but it should be the most economical method of doing the particular effort. A logical question at this point might be: How do you teach students to be economy minded? In industrial engineering this is done by subjecting the student to a course in engineering economy early in his career and making frequent use of engineering economy principles in other courses.

This typical engineering economy course might include the following topics:

1. Interest, equivalence, and depreciation
   a. Interest and interest formulas
   b. Calculations of equivalence involving interest
   c. Depreciation and depreciation calculations
2. Planning engineering economy analysis
   a. Classifications of cost for economy analysis
   b. A pattern of engineering economy analysis
   c. Treatment of estimates in engineering analysis
3. Engineering economy analysis and evaluation of alternatives
   a. Basis for comparison of alternatives
   b. Break-even and minimum cost analysis
   c. Evaluations of replacements
   d. Economy in the utilization of personnel
   e. Evaluation of public activities
4. Accounting, cost accounting, and income taxes
   a. Accounting, cost accounting and economy analysis
   b. Income taxes in economy analysis
   c. Evaluation of existing operations
   d. Evaluation of proposed operations

Perhaps the most valuable of these topics is the evaluation of alternatives and, in truth, this is what an engineer does in every case. He is always deciding what materials to use, what size to use, what type to use, etc. This type analysis attempts to give the engineer a background in the financial portion of the picture so that he might construct the most economical system—not just a system that works.

It is obvious that there are many examples of engineering economy in highway engineering and maintenance work. We do not have to go far afield to find examples of how the highway maintenance engineer would use engineering economy. Probably the most common application would be in the justification for new equipment. The engineer would list the alternatives of not having the equipment. These alternatives may include doing the work with manual labor, doing the work with other types of equipment, doing work with the equipment that is on hand. The engineer would then draw up the alternatives and cost of the alternatives would thereby give the decision-maker all the information he needs to decide which would be the most economic course of action to take. There are many other examples of engineering economy in highway maintenance work but these are too obvious to require illustrations.

PLANT LAYOUT—MATERIALS HANDLING

Traditional plant layout courses teach the industrial engineer the most efficient way to place production equipment within the plant. This usual course is heavily slanted towards the hard goods industry, thus the problems faced by the industrial engineer include situations involving lathes, drill presses, etc. At LSU, we recognize that our graduates will be more interested in the process-type industry; therefore, we slant our courses more toward the chemical-type industry. Part of any plant layout course includes techniques and methodology in materials handling. Materials handling is of great interest to highway maintenance engineers. A large percentage of highway maintenance cost includes the transportation and handling of material and the most efficient ways to perform these operations should be of great interest to all involved.

Applications of plant layout by itself are relevant to highway maintenance in that most maintenance districts have a central shop or repair area where the principles of plant layout can yield a more efficient system. My experience indicates that shop areas merely grow and no overall plan or thought is given to their layout.

Aggregate, asphalt, concrete, steel sections for bridge repair and railings, mulches, fertilizers, water, and sign material are examples of the types of material with which highway people must cope. It is therefore essential that highway maintenance people be familiar with the latest types of equipment so that the most economical materials handling system can result.

STATISTICS AND OPERATIONS RESEARCH

The preceding technologies are more or less traditional approaches to the field of industrial engineering. Most of the new work and horizons in this area are in the field of statistics and operations research. Statistics is both an art and a science, and it deals with the collection, tabulation, analysis and interpretation of quantitative and qualitative measures. It is concerned with the classifying and determining of actual attributes as well as the making of estimates and the testing of various hypotheses by which probable, or expected, values are obtained. It is one of the means of carrying on scientific research in order to ascertain the laws of behavior of things. Statistics is the technique of the scientific method.

Statistics is a branch of applied mathematics. It differs from so called pure mathematics in that the values in statistics are approximations or estimates, but not mere guesses.

Statistics deals with problems that fall into two general categories. The first has to do with characterizing a given set of numerical measurements or estimates of some attribute or set of attributes applying to an individual or a group of individuals. In highway maintenance work, the statistical situation might be characterized by our making estimates on the probable use of materials for a particular district or a particular state.

The other category has to do with characterizing an attribute or attributes belonging to all individuals of the group one is investigating. In highway maintenance engineering, this might be an attempt to predict overall maintenance costs for the whole country or the creating of standards which would apply to the entire Interstate System and problems of this nature.

Statistics, then, is the science of obtaining more information out of a set of data than we would normally obtain. If there is one word which characterizes statistics, that word is prediction. If we want the ability to predict the future behavior of any situation then we must use statistical methods to try and ascertain the degree of consistency with which we can predict; therein lies the secret of why we use statistics. We can put a number in it to indicate the degree of consistency we have in the data which come from any sample large or small.

One branch of statistical methods which appears to be having a field day in the field of highway maintenance work is that of regression analysis. In regression analysis we take a group of variables and try and find out the effect of those variables on what we are trying to measure. For instance, if we are trying to measure total maintenance cost for the highway system, variables such as traffic right-of-way width and surface width are all characteristics which may or may not affect the cost of maintenance. The regression appraoch will tell us to what extent each of these variables affect maintenance costs. Therefore, if we had limited funds to spend on maintenance and we had a regression analysis of our system we would find out where each dollar would do the most good. Th results of regression analysis are mathematical models. Many people have the feeling that mathematical models are a very popular thing and many of us deplore the fact that they perhaps have been overused. This is only natural where a group of scientists or engineers discover a new technique. The technique may be overworked in its initial stages. I will not dwell further on statistical techniques, but the time spent here in discussing them is not proportional to their value. There are many more applications of statistical methods in highway maintenance work.

Closely related to statistics is the emerging field of operations research. This tool represents a very significant advance in the engineer's ability to try and appreciate the environment with which he is working. Operations research tackles large-scale problems which normally are not solved manually, but need electronic data processing equipment.

Operations research involves the application of mathematical techniques to the front-line, nuts and bolts problems of industry, operational problems as diverse as, but not restricted to, labor distribution, profitable inventory levels, price quotations, production planning, maintenance planning, etc. It consists of correlating all available data on a problem and providing management with factual, quantitative reports on the relative merits of all potential courses of action.

There are a number of techniques which are generally recognized as being the core of any operations research study. The first is linear programming. Linear programming is a mathematical technique whereby the best allocation of limited resources may be determined by manipulation of a series of linear equations. This technology, of course, has every widespread use in the highway maintenance field and is being used today. Some problems which could be solved in this manner are problems such as where to locate a highway maintenance storage area for the minimization of travel time to the possible points of use of the material which is stored there. Also, the technique that could minimize the travel time for trucks and other roadbuilding equipment.

Another technique is called queuing theory. This situation takes place when the flow of materials or people is bottlenecked at a particular servicing point. Here, losses occur in the form of lost time, idle equipment, and unused labor. Minimizing such costs is the job of queuing theory. In the highway maintenance example, this could take place where people had to wait because the number of trucks or pieces of mechanical equipment was not satisfactory in order to keep everyone busy.

Another example is the following: What is the expected length of a line when 29 workmen arrive randomly each hour at a tool store where the store man takes an average of two minutes to serve each man? Queuing theory predicts that the line will settle down to an average length of 28 men and an average waiting time of 58 minutes. In each hour, then there would be 28 man-hours lost in waiting. Further calculations show that one extra store man will reduce the average to 0.28 man, releasing 27.3 men for productive work. Addition of a third man, however, will only cut the average to 0.04 and might not be justified when weighing the third man's salary against the production time gained.

There are other techniques in operations research such as game theory, dynamic programming, and simulation techniques, but these techniques are so theoretical that there are not many examples in highway maintenance work. This does not mean that the techniques are useless. It merely means that our state of knowledge has not reached the point where we can apply these techniques to the specific problem that we have in highway maintenance.

In summary, I have attempted to give an idea of how some industrial engineering techniques can be useful in highway maintenance operations. The list of applications is a long one, and only a few of the techniques which could be useful in this type of work have been covered.

There is much need for industrial engineers in state highway departments in general, and in maintenance operations in particular. Tradition dictates that state highway departments hire mainly the civil engineer. It is difficult to understand why this practice persists, when, in a number of positions, the job demands knowledge in the scheduling, planning, and budgetary fields much more than a knowledge of concrete and reinforcing rods.