HIGHWAY RESEARCH RECORD

Number 278

Highway Equipment Studies,
Construction Management,
Noise and
Air Pollution Bibliography

7 Reports

Subject Area

33 Construction
40 Maintenance, General
41 Construction and Maintenance Equipment

HIGHWAY RESEARCH BOARD

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Special Committee on Highway Equipment

(As of December 31, 1968)

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Foreword

Contractors, maintenance engineers, specification writers, materials engineers, safety engineers, and purchasing agents will find information of interest in this RECORD.

Two reports are concerned with equipment noise. Many European countries regulate construction working hours because of the noise concomitant to construction operations and some United States communities have imposed restrictive measures but, by and large, United States noise control laws have not been widely enacted. Current trends indicate that the situation is changing, and users of construction equipment probably should seriously consider equipment noise as a controllable aspect of construction noise. New York, in 1965, enacted a state law setting a limit of 88 dBA for truck noise. California recently enacted a law setting a standard of 92 dBA for trucks moving faster than 35 mph.

Steady noises above 85 dBA are capable of producing hearing loss, and the risk of loss cannot be reduced except by reducing the noise exposure. There is no way to restore the hearing loss. Botsford has stated, "Noise reduction is generally considered the responsibility of the employer," and "Both manufacturers and operators of noisy equipment should eliminate objectionable noises where practical." Again, "Purchasers can encourage manufacturers of noisy equipment to produce quieter products by requesting that product noise data be supplied with quotations or by including noise specifications in purchase requisitions...purchase orders have specified maximum octave-band noise levels equivalent to about 90 dBA at the operator's location."

Groening, of GM's Noise and Vibration Laboratory, addresses the problem of quieting heavy equipment and discusses some known ways of bringing the noise under control.

Nationwide interest by a concerned public is also forcing development of air and water pollution control measures in the form of legislation, zoning ordinances, and other means. Construction operations are not immune to such pressures. For that reason, the Highway Research Board's Special Committee on Highway Equipment deemed it desirable to publish a selective bibliography on the subject of air pollution as a ready reference. A wide audience should find the bibliography useful.

Government officials have always found it difficult to reconcile manufacturers' claims to superior equipment performance. Consequently, over the years conventional practice has not been to write equipment performance specifications, but instead to outline specifications within the limits of which a number of manufacturers can offer competitively priced equipment. Under an evolving concept known as total cost bid, or performance bid, a manufacturer can offer a guarantee that the total cost of the equipment including maintenance and downtime over a specified time span will not exceed a stated figure;

thus, more durable and possibly more expensive equipment items are not penalized in the bidding process. The potential for this system of equipment procurement is explored in a paper by Hughart with a discussion by Doom.

A number of investigators are actively engaged in using analytical methods in construction management. One of the most interesting current efforts, because it systematically brings numerous concepts together, is under way at the University of Illinois. A number of contractors have stored their records in the school's computer memory; from the stored data a comprehensive construction management system is being evolved. Froemming and Fenves describe the data structures for accounting, payroll, CPM, and estimating in their paper—activities that are already in an on-going status and being usefully applied by the contractors who financially support the system.

E. A. Cox offers another illustration of the use of equipment records stored in a computer data bank in his paper, "Information Needs for Controlling Equipment Costs."

Conclusions derived from equipment production studies made by the Bureau of Public Roads during the last 20 years have been previously published in HRB Special Report 68 and Highway Research Record 160. Over the years these studies have been widely distributed and studied by contractors; undoubtedly construction efficiency has been substantially improved as a result of the Bureau's work. The studies have been curtailed in recent years because of personnel shortages, primarily because trainees newly hired by the Bureau are no longer available for production studies. However, Kilpatrick and Records have summarized the average production per hour of productive time, net available working time, and scheduled shift time for approximately a dozen classes of equipment. This summary should prove to be a valuable supplement to the reports that have preceded it.

Contents

Highway Construction Equipment Noise Hazards

JAMES H. BOTSFORD, Noise Control Engineer, Bethlehem Steel Corporation

•PROLONGED exposure of personnel to the intense noise produced by diesel-powered highway construction equipment can cause partial deafness. This noise-induced hearing loss accumulates gradually without being noticed over years of exposure, and the susceptibility of individuals to it varies widely. It is permanent and cannot be corrected by any known medical treatment or by using a hearing aid. It is a compensable occupational disease in many jurisdictions, and some states have adopted regulations intended to control occupational exposures that can cause it. The best method of prevention is to eliminate harmful noise exposures by engineering methods or operating procedures. Where these measures fail, personal protective equipment can be used as a last resort.

MODERN NOISE MEASURE

Noise is a slight, rapid variation in atmospheric pressure. The size of the pressure variation, which is measured as the sound pressure level in decibels, increases with the loudness of a sound. The rate of recurrence of the pressure variation, which is measured as the frequency in cycles per second, increases with the pitch. Most noises are the result of many pressure variations at different levels and frequencies occurring simultaneously.

Both level and frequency of a noise must be considered in determining the probable effect on hearing. Traditionally, an octave band noise analyzer was used to divide the noise spectrum into 8 or 9 contiguous frequency ranges and measure the sound pressure level in each of these bands. Octave band analysis is still needed for some engineering applications, but is no longer required for appraising noise hazard. Recently, it has been shown that the sound level measured using the A-weighting network of a standard sound level meter provides an accurate index of noise hazard. Fortunately, the A-weighting network makes the meter less sensitive to low-frequency sounds in much the same way that the ear is less sensitive to injury by these low-frequency sounds. This practicable single-number evaluation of noise can be made by personnel having little special training using a simple sound level meter.

The A-weighted sound levels in decibels (abbreviated dbA) measured at operators of highway construction equipment are given in Table 1. Different levels were found at different machines of the same type, and the range is given. Normal operating conditions prevailed during these measurements, and much lower levels were usually found during lulls in operations.

NOISE EXPOSURE INCREASES PREVALENCE OF HEARING IMPAIRMENT

It has already been pointed out that not all persons are affected the same by noise. Some retain perfect hearing in noise exposures that cause hearing losses to others. Many become hard-of-hearing without noise exposures, due to diseases and other deleterious influences. Because of these individual variations, the effect of a noise exposure on a group is better described by the portion of the group affected significantly than by the average effect. For the purposes of this discussion, development of a hearing impairment as defined by the American Medical Association will be considered a significant effect, and the hearing deficiency of a group will be described by the percentage of the group having such an impairment to any degree.

Paper sponsored by Special Committee on Highway Equipment.

TABLE 1

SOUND LEVELS AT OPERATORS OF HIGHWAY CONSTRUCTION EQUIPMENT

Equipment	Sound Level (dbA)
Trucks (15-ton up)	89-101
Shovels	91-107
Bulldozers	102-106
Cranes	88-99
End loaders	95-97
Graders	91-96
Scrapers	99-102

The effects of noise exposures on personnel as revealed by various hearing surveys are summarized in Figure 1. Each data point indicates on the vertical scale the percentage found to have impaired hearing in a group exposed continuously at work to the A-weighted sound level indicated on the horizontal scale. For each age group, the curve drawn through the data points rises with increasing sound level from a minimum value corresponding to the incidence of hearing impairment in the general population not exposed to harmful noise at work.

The curves of Figure 1 indicate the risk of hearing impairment associated with a particular noise exposure. For example, the upper curve shows that a group aged 50 to 59 years that has been exposed for 33 years to 89 dbA should contain 27 persons with impaired hearing for every 100 persons exposed. The lowest portion of the same curve indicates that 20 out of 100 persons in that age range should have impaired hearing without occupational noise exposure. As diseases and other factors that produce hearing impairment in the general population likewise affect those exposed to noise at work, the net effect of 33 years exposure to 89 dbA should be enough to cause 7 more cases of impaired hearing in every 100 persons exposed than would otherwise have existed. For the younger age groups exposed for shorter periods, the net effect would be even less.

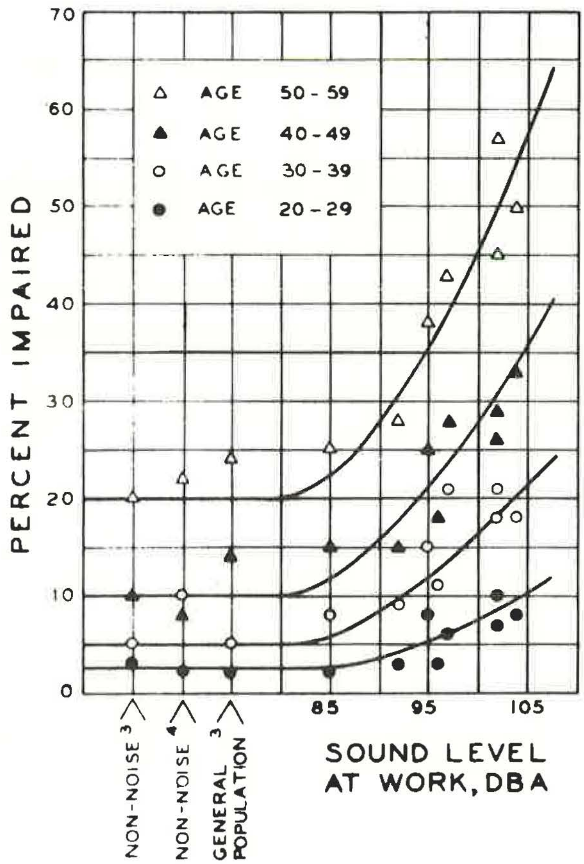


Figure 1. Prevalence of impaired hearing in various groups.

INTERRUPTING NOISE EXPOSURE GREATLY REDUCES HAZARD

When harmful noise is interrupted, the ear can rest and recover somewhat from the effects of the noise. Periodic interruption of noise, therefore, reduces the hazard and permits the ear to tolerate the noise for a longer total duration without increased risk of injury. Figure 2 shows how rapidly the total noise duration tolerable increases with the number of equally spaced interruptions occurring in a day. Some of the curves pass through maxima, indicating that the allowed exposure duration is maximum when rest periods having the optimum length of 5 minutes are properly spaced throughout the day.

To determine whether a noise exposure is acceptable according to Figure 2, count or estimate the number of times during the day when the sound level drops to 89 dbA or less. These interruptions of exposure are presumed to be approximately equally spaced. Use the number of interruptions together with the average A-weighted sound level in between them to find, from the curves of Figure 2, the total duration of noise above 89 dbA that is acceptable.

As an example, consider the noise exposure of a truck driver who hauls rock from a cut to a fill area. Suppose it takes 10 minutes to haul out of the cut during which time the average sound level in the cab is 104 dbA and 5 minutes to return to the cut during which time the average cab sound level is 98 dbA. When waiting at the shovel for the next load, exposure is interrupted because the noise in the cab measures 73 dbA. About 30 loads are hauled every day, and Figure 2 indicates that 104 dbA interrupted 30 times per day should last no more than 200 minutes total. As the noise actually lasts about 300 minutes total, the exposure should be considered harmful and steps taken to reduce it.

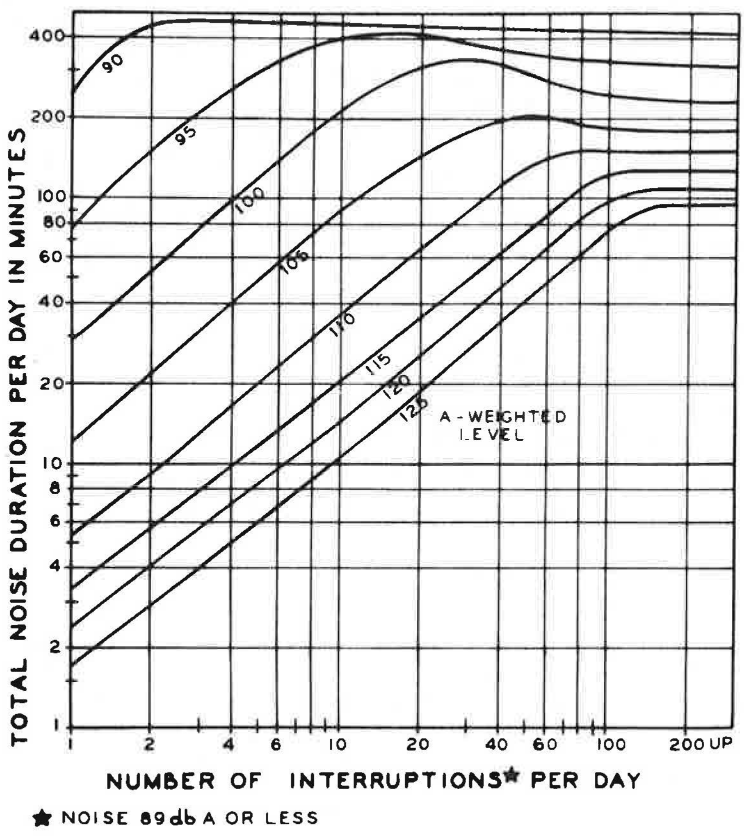


Figure 2. Acceptable daily noise exposures.

The incidence of hearing impairment in a group exposed to any noise pattern allowed by Figure 2 should be slight. The greatest level allowed for continuous all-day exposure (one interruption per day) is 89 dbA, and it has already been observed that the net increase in incidence of impairment due to this noise exposure is quite low. Since all other patterns of noise exposure permitted by Figure 2 are equally harmful and create the same risk for a group exposed, the incidence of hearing impairment resulting from any of them should be equally low.

Interpreting the construction equipment noise levels of Table 1 in the light of Figure 1, it is clear that some operators might be expected to develop impaired hearing. Hearing tests conducted on groups of operators have shown this to be the case. Considering the intermittent nature of some construction operations, Figure 2 would imply that the hazard of the associated equipment noise would be reduced. Hearing surveys have verified this effect also.

NOISE CONTROL PRINCIPLES CAN BE APPLIED TO CONSTRUCTION EQUIPMENT

The principles of noise control are well understood and can be employed to reduce noise of construction operations. The pulsations in atmospheric pressure that the ear perceives as noise may originate with an aerodynamic disturbance such as the turbulence produced by the engine cooling fan. More often, noise is generated by the vibration of some structure that produces sound waves in the adjacent air. In either case, it is obvious that noise generation can be reduced by lessening the disturbance causing it, whether it be turbulence or vibration.

Vibration of a structure is quite dependent on the rigidity that is usually prescribed by non-acoustical considerations. Given a structure with its vibration characteristics, there are two types of materials that can be used to control vibration. One is a soft material like rubber that reduces the transmission of impact or vibration from one point to another by yielding rather freely to the impressed forces. The other is a viscous or frictional material like automotive undercoating that is applied to the structure to create resistance to the vibratory motion.

Similarly, there are two types of materials to control sound escaping from a source. One is a solid material like steel that blocks transmission of sound. It is impermeable by the pressure pulsations of the sound waves and unyielding to the forces they produce because of the rigidity and inertia. The other sound control material is porous, allowing incident sound waves to penetrate and be absorbed or dissipated by resistance to air flow through the pores of the material. These materials are utilized in the construction of engine exhaust mufflers that effectively minimize the escape of exhaust pulsations.

Proper use of these materials can reduce equipment noise. It is first necessary to analyze the noise source to determine how the noise is generated and transmitted to the operator. Then the materials should be used as required to block sound, block vibration, absorb sound, or absorb vibration.

For highway construction equipment, installation of an effective muffler on the engine exhaust provides most of the noise reduction required. The additional noise reduction needed can usually be obtained by improving the acoustical effectiveness of barriers separating the operator from the engine, and by adding sound-absorbing materials to the engine and operator compartments.

MANUFACTURERS CAN QUIET NOISY EQUIPMENT

Purchasers should encourage manufacturers of noisy equipment to produce quieter products by requesting that noise information be supplied with quotations or by including a noise specification in purchase requisitions. The manufacturer should accept responsibility for providing the noise abatement required, because he is in the best position to develop the modifications needed. Furthermore, under recent decisions involving product liability, a manufacturer may be liable for hearing loss caused by a product that is capable of producing noise of injurious levels. There is usually a greater awareness of the need for quieter products among users and they should help manufacturers to understand and meet their noise requirements.

This approach has been successful in obtaining quieter construction equipment. In purchase orders, maximum octave band levels at the operator location were specified that corresponded to a sound level of about 90 dbA. Usually, only minor modifications of standard vehicles were necessary to meet this noise requirement. The average noise reduction obtained with these modifications was 8 dbA. All major manufacturers of construction equipment have supplied quieter models at reasonable additional costs, and several are giving careful consideration to noise in the design of future models. None of the equipment recently purchased using the noise specification produces harmful noise exposures.

EAR PROTECTION IS LAST LINE OF DEFENSE AGAINST NOISE

When potentially harmful noise exposures are unavoidable, ear protection may be used to reduce noise entering the ears. Two types are available: plugs to be inserted in the ears and muffs that cover the ears. Either type must seal off the ears almost air-tight in order to be effective.

Rubber-like plugs for insertion in the ear canal are available in several configurations. Up to five graduated sizes are needed for fitting the range of ear canal sizes encountered in a large group. There is no reliable way to determine when a plug fits the ear canal properly except by a sound reduction test. Hearing thresholds measured with an audiometer before and after insertion of the plug will indicate the attenuation by the plug of sound entering the ears. The difference between these hearing thresholds in decibels should be approximately equal to the noise reduction reported by the manufacturer when the plug occludes the ear canal properly.

Recently, a mineral wool composed of very fine fibers has been marketed by at least two suppliers for the use as an ear protector. Noise reduction tests have shown that, when it is properly packed into the ear canal, it excludes noises as effectively as other types of plugs. Individual fitting is not required and greater comfort is reported by most users.

Muffs covering the entire ear afford more reliable ear protection because adequate seal of the cushion against the head is readily attainable. Muffs, however, interfere with anything worn on the head, particularly those muffs having a band passing over the head. Models for attachment to a hard hat are available, which partly eliminates this interference. Least interference is encountered with the muffs held in place by a band passing behind the head. Individual fitting of muffs is rarely required, and it is easy for supervisors to see whether employees needing this type of protective equipment are wearing it.

Sound Reduction of Earth-Moving Machinery

JAMES A. GROENING, Noise and Vibration Laboratory,
General Motors Proving Ground

•IT HAS BEEN pointed out by others that the demand for quieter heavy equipment is not consistent with some requests made in the past. Many persons in the heavy machinery and heavy highway truck manufacturing business have told me how operators associate noise with power. The straight exhaust stack truck has apparently long been the ultimate in truck driver's exhaust systems. I believe this era is coming to an end.

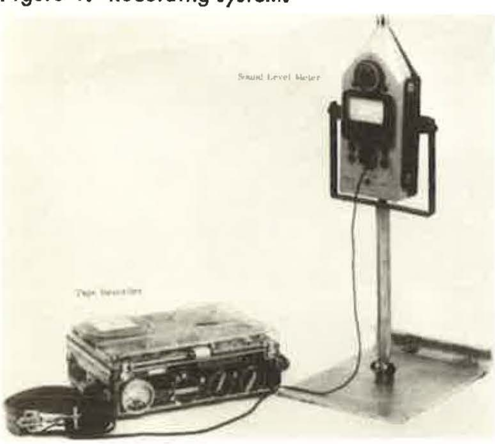
Many reasons can be cited for the increasing interest in noise control of earth-moving machinery. Size of such machinery in terms of either load capacity or engine horsepower is increasing faster than most imagined 10 years ago, and indications are that further increases in size can be expected. Use of multiple engines in a single vehicle can result in special sound effects that are particularly undesirable.

In the past, the smaller machinery then in use probably did not produce noise levels much greater than heavy traffic in urban areas. Now, the large size and numbers of machines used on a single job may produce sound levels much greater than the background. Our living in suburbia has affected the requirements for noise control also. It is difficult to be out of earshot of a subdivision these days when building a highway or a shopping plaza anywhere within 40 miles of any large city.

Besides these factors, the exponential increase in numbers of powered equipment of all types has caused noise to become a factor that society as a whole takes exception to. Our customers have for a long time expressed their interest in silence by choosing automobile models that provide extensive noise control treatment. Thus, it is not too surprising that quieter earth-moving machinery is in demand.

We have recognized noise as a potential problem for several years and have been accumulating noise data on various earth-moving machines. For the past three years, noise produced by every machine assigned to operate at the GM Milford Proving Ground has been measured. Certain of these machines were selected by Euclid Engineering to use in pilot projects to determine the means required to significantly reduce noise. Front loaders, rear dump trucks, and a crawler tractor were studied.

Figure 1. Recording system.



NOISE SOURCES AND THEIR CONTROL

To date, these studies have involved primarily only the engine and its accessories as noise sources. Studies of the noise due to operations such as loading, scraping, and dozing have not yet been made

Noise at operators' stations and the noise heard by an observer at some distance from the vehicle usually must be considered separately. Although the same sources are

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Figure 2. Playback and analysis system.

responsible for noise at each of these locations, the manner of treatment required may not be the same.

Instrumentation

The basic instruments shown in Figure 1 were used throughout the program to record noise. Data signals from the sound level meter were usually recorded on the tape recorder. Later the tapes were played back through the octave band analyzer (Fig. 2) to determine frequency content. Playback listening comparisons were used also to define noise sources and to evaluate changes.

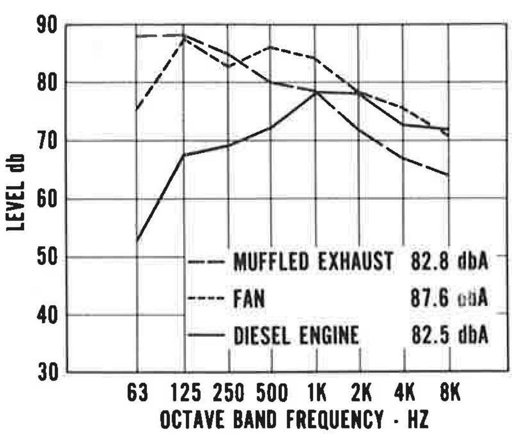

Figure 3. Noise level of components at 50 ft.

Exhaust Noise

Exhaust noise is probably the most obvious to most persons acquainted with earth-moving machinery. From a technical standpoint, however, it is also one of the most easily reduced. Furthermore, significant overall noise reduction cannot be achieved without adequate exhaust noise control. Mufflers that adequately reduce exhaust noise are generally available for any degree of silencing required. More silencing, of course, requires a larger, more expensive muffler. Figure 3 shows the noise level measured at a distance of 50 ft for a well-muffled exhaust. A fan spectrum is also shown along with that of a diesel engine with no fan and with intake and exhaust silenced. The exhaust noise is lower than the other components shown over at least part of the frequency range.

Cooling Fan

Cooling fans generate considerable noise as can be seen from Figure 3. Each time a blade passes a certain point in its rotational travel, a disturbance is caused in the air. This results in a fundamental frequency corresponding to blade passage. Many multiples of this frequency are produced, as well as aerodynamic flow and vortex noise. This results in the broad frequency spectrum of noise shown. The data were taken 50 ft from the coolant radiator end of a front loader.

To reduce the noise to a certain intensity, the engine compartment in which the fan is located can be enclosed with a hood and side covers, with air ducted around the bottom of the enclosure. If the sound at the operator's location is the problem, the radiator must be located so that noise from the fan and other components must travel a maximum distance to get to an operator. Sound absorptive linings inside the engine enclosure also are beneficial in reducing the higher frequency parts of fan noise. Accoustically treated louvers outside the radiator can be used to reduce noise radiation in that direction.

Noise Radiated by Engine

The engine itself is a significant noise source in some cases. Because of the high combustion pressures and rate of pressure rise in diesel engines, they are usually noisier for a given output than is a gasoline engine. The firing of the engine and other dynamic forces generated causes forced vibration and may excite resonant modes of engine block walls, rocker arm covers, and other components, such as the clutch housing, transmission, intake silencer, and exhaust piping. The spectrum of noise shown in Figure 3 is that radiated by a diesel engine running on a dynamometer with intake and exhaust greatly silenced. Engine noise can be a problem for an operator whenever a cab or the operator is in very close proximity to the engine itself, and particularly if the engine is not enclosed.

Vibration of the engine caused by dynamic forces can result in excitation of a vehicle frame and this, in turn, will cause any sheet metal, attached to the frame, such as a cab or engine enclosures, to vibrate also. Any vibrating panel, of course, radiates noise. With proper design, use of fairly stiff isolators to maintain good control of the engine can still result in good isolation over the audio frequency range.

Combustion Air Intake Noise

The combustion air intake of an engine can produce nearly as much noise as the exhaust. Among other factors, intake noise is dependent on the type of air cleaner used and the character of connections. At times the mounting of the intake silencers and the associated piping can cause some noise problems by causing vibration of a cab or other sheet metal components. Also, any ducts between the air cleaner and the engine that are flexible, such as those made with thin rubber, are quite transparent to noise and could allow radiation of noise through them.

Accessory Noise

Within the classification of accessories are transmission, pumps, generators, compressors, etc. Many of these generate very large dynamic forces. Mounting of oil or hydraulic equipment, such as filters or coolers, directly to flexible sheet metal can result in vibration and thus radiation of noise. When such equipment is either mounted directly to the heavy frame or mounted on isolators, the vibration and noise radiation can be reduced.

Operator Location Noise

Often, in heavy equipment, the sources that are important in producing noise at the operator location are not the same as those that are problems from an annoyance standpoint as heard some distance from the vehicle. In some cases, good control of operator noise can be achieved without affecting the noise level heard by observers.

Exhaust noise generally heads the list on present equipment for noise at the operator location. It should be pointed out, however, that in many cases there are other sources

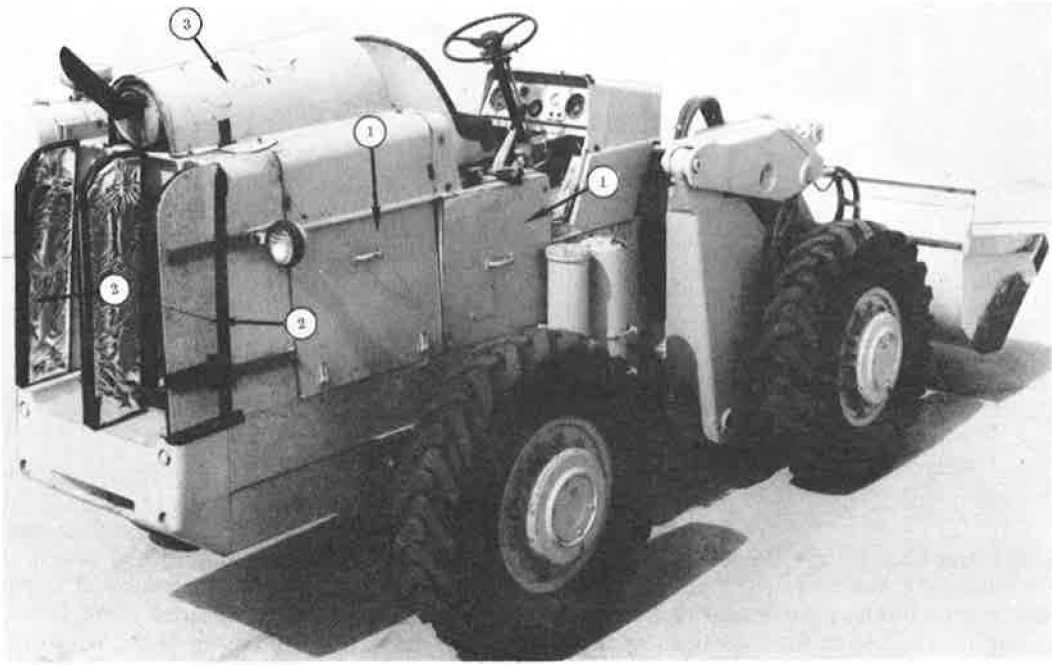

Figure 4. Experimental treatment on front loader.

that are as loud or louder than the exhaust at the operator's location. Reduction of all the significant sources must be achieved simultaneously or little actual noise reduction will be apparent.

Cooling fan noise has been found to be very important on some equipment, such as small front loaders and on crawler tractors where the operator location is close to the fan. As mentioned, one means of controlling the cooling fan noise at the operator location is to increase the effective path length of the sound between the fan and the operator. Figure 4 shows a means of doing this on a front loader vehicle. The figure shows the external appearance of a Euclid front loader complete with experimental noise con-

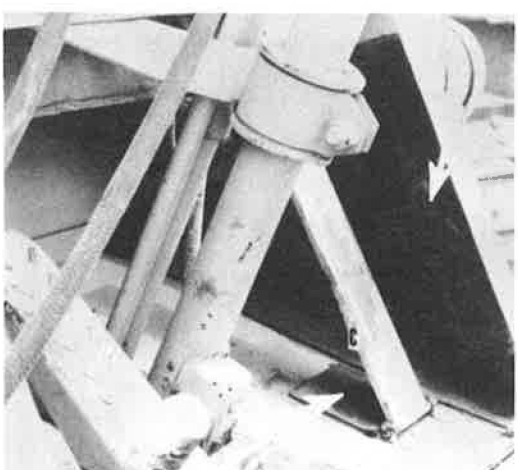

Figure 5. Sealing flap in foot well.

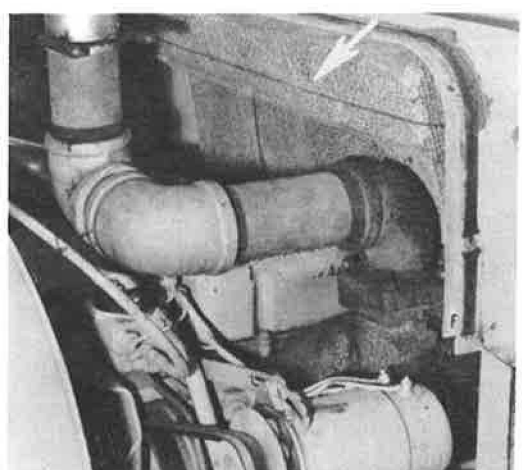

Figure 6. Screen-covered sound-absorbing material in engine compartment.

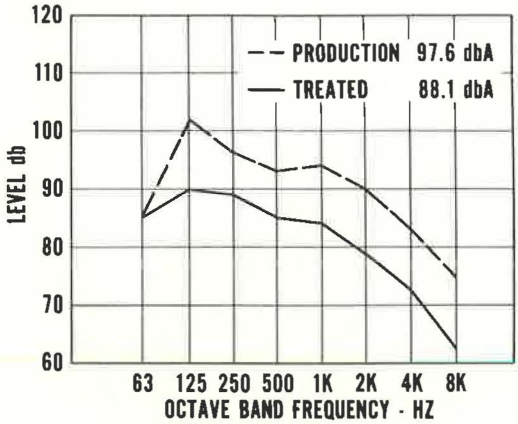

Figure 7. Location noise-loader.

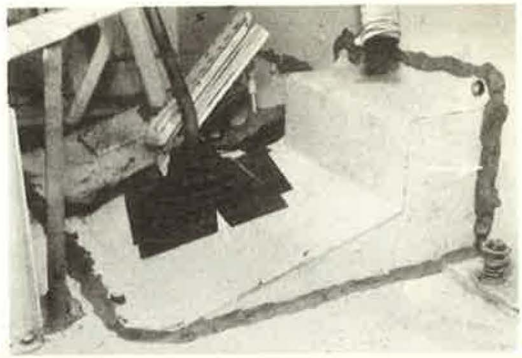

Figure 8. Sealing between cab and engine.

trol accessories. Engine covers are shown by the No. 1 arrows, cooling air outlet louvers by No. 2 arrows, and experimental muffler and hood by the No. 3 arrow. Figure 5 shows where sealing flaps were added at the driver's foot and control locations. The type of sound-absorptive treatment used in the engine compartment shown in Figure 6, was screen- and foil-covered fiberglass. The engine enclosure also reduces accessory noise. Normally the sides of the engine are uncovered and the exhaust outlet and inlet stacks are closer to the operator location. The noise path from the cooling fan, engine, and accessories would normally be out the sides of the engine compartment and directly to the operator. Figure 7 shows the operator location noise reduction achieved by these measures. Nearly 10 decibels sound level reduction was achieved as measured on the A-scale of a sound level meter.

Another development program was conducted on a Euclid rear dump truck. The muffler was relocated; the engine, oil filter, and accelerator control were mounted using rubber isolators; sealing of cracks between the cab and engine compartment was added; and acoustically absorptive treatment was installed in the engine compartment and inside the cab. Figure 8 shows the nature of the sealing, including a shift lever boot, added to the cab. Figure 9 shows some isolators used to mount an oil filter. In Figure 10 the foil-covered fiberglass hood liner used for these tests is shown. These

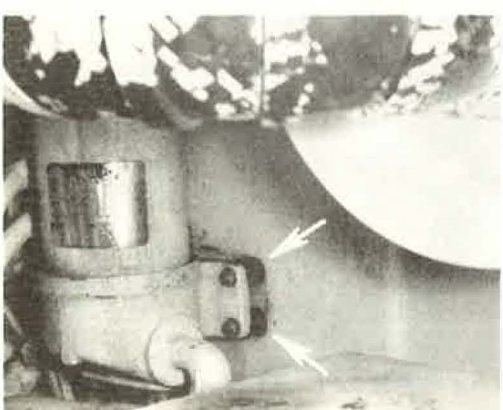

Figure 9. Isolated oil filter.

Figure 10. Foil-covered fiberglass hood liner.

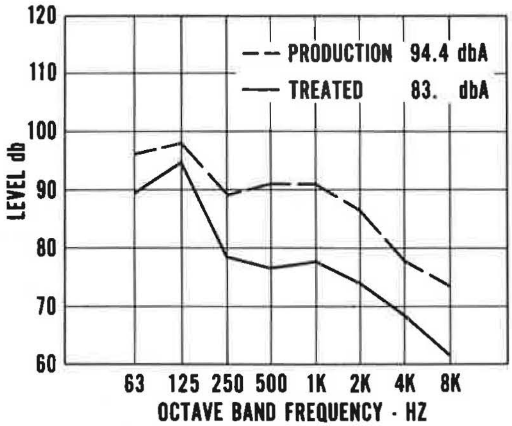

Figure 11. Operator location noise—truck.

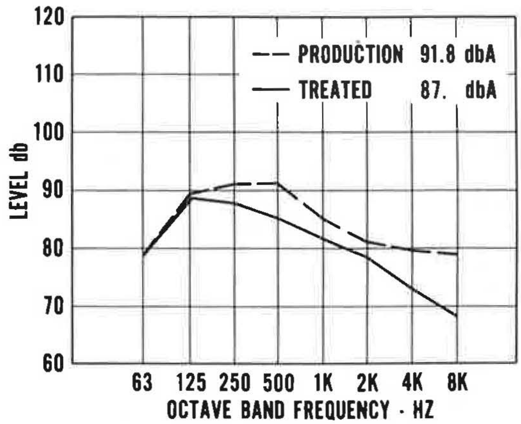

Figure 12. Noise during passby—truck at 23 ft.

changes resulted in the operator position noise reduction shown in Figure 11. A reduction in sound level greater than 11 decibels resulted, as measured using the A-scale.

Cabs on machines may be isolation-mounted instead of, or in addition to, the engine isolation. In the past, soft cab mounts have usually resulted in undue pitching of the cab during operation on some terrain. But with proper design this need not be so, and more isolation-mounted cabs will probably be seen in the future as advanced technology is applied to the problem.

OBSERVER NOISE CONTROL

Experience to date with earth-moving machinery has shown that exhaust and cooling fan noise have been the major problems as an observer hears a vehicle. Radiation directly from diesel engines causes a distinct sound that is annoying to some primarily because of its character.

It has also been found that use of turbo-chargers may result in some objectionable noise. Sometimes this is because no mufflers are used, and sometimes because the turbo-charger operation results in excessive whine. We have found in some recent experiments that rather simple, although large, mufflers can be used on turbo-charger exhausts. These produce very little back pressure, but greatly reduce low-frequency exhaust noise as well as high-pitch whine.

The changes made to reduce noise at the operator's location on the Euclid truck resulted in less difference at an observer's location. Figure 12 shows this difference to be about 5 db as measured on the sound level meter A-scale.

In summary, a few comments about future trends are called for. It has become apparent that concern about environmental conditions is becoming our society's present preoccupation. We expect to see more and more requests for quieter equipment of all sorts. We have our job cut out for us, since the size and number of units produced will certainly be on the increase. To counter this, fundamental studies are being conducted and more are planned to reduce noise at the source. The engine itself is receiving considerable attention; novel cooling fans and fanless cooling systems are under study, as are unique exhaust muffling systems. By far the greatest benefit will accrue from the application of fundamental noise-control techniques on the drawing board as new models are planned. It is a fascinating and challenging opportunity.

Bibliography on Air Pollution

•NATIONWIDE interest in air and water pollution is resulting in national and state legislative acts, local zoning ordinances, and other measures, many of which restrict such construction operations as crushing plants and hot-mix asphalt plants. The result is additional expense to the supplier of construction materials and ultimately to the public. Conflicting codes complicate the problem for contractors operating in two or more areas.

Members of the Committee on Highway Equipment recommended publication of a selective bibliography on air pollution as a reference for authorities responsible for setting air pollution standards. The Committee is indebted to H. I. Hansen and F. A. Renninger for assembling the bibliography.

A Compilation of Ambient Air Quality Standards and Objectives. U.S. Department of Health, Education and Welfare, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, May 11, 1965.

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Purchasing Equipment for Public Works on Total Cost Bid

W. M. HUGHART, Caterpillar Tractor Co.

•THIS year, state and local government agencies in the United States will spend nearly a billion dollars on equipment for maintaining their vast network of streets and highways. And, so that 200 million U.S. citizens will get the most out of taxes they pay, the majority of this equipment will be purchased on competitive bid.

For some time now, government officials and in particular engineers, public works directors, equipment superintendents, and others who work closely with heavy equipment have become convinced that buying the lowest priced machine meeting the specifications can result in high repair costs, excessive downtime, and less than anticipated resale value at trade-in time. That this situation exists in many governmental bodies all over the country can be verified by a simple perusal of equipment cost records.

Table 1 gives an example of the difference in the cost of operating machines that were purchased on the same specifications. Note the wide variance in repair costs. A 50 cents per hour higher repair cost results in $5,000 higher cost over 10,000 hours, a typical amount of usage in 10 years for a road grader. And, even if it costs $5,000 less initially, what about downtime? A machine that costs more to repair is going to be down more of the time and consequently not available to do as much work. There is also resale value to consider (Fig. 1). The best indication of resale value is how much it will bring on the auction block. Comparing resale values on this basis eliminates any hidden discounts, sales gimmicks, or other procedures designed to make one machine more attractive to prospective buyers. The selling price of a machine sold at auction is based purely on how much the bidders are willing to pay for it—how long it will run in its present condition or what it will cost to put it into working condition. The bidders know from experience what these machines cost to own, operate, and repair, and they bid accordingly. Records published by Forke Brothers of Lincoln, Nebraska, world's largest auctioneer of heavy equipment, show a considerable difference in the resale value of different makes of machines.

One might ask, "Why are government agencies not allowed to purchase equipment like contractors do?" Actually, almost without exception, the laws governing purchases by government agencies allow some discretion in awarding the bid. Such phrases as "lowest and best", "considering all factors", or "lowest ultimate cost" are common. Why then, is there so much emphasis placed on low bid? Who is really to blame for the tax dollars wasted on low bid equipment that breaks down under hard use?

Some say the purchasing agent or county commissioner who has final responsibility for the purchase is at fault. It is claimed that these individuals are not familiar with equipment and rely too heavily on specifications, to which they reply, "Why don't you learn to specify what you want?" The elected official must also consider the publicity he will surely get if he does not buy on low bid. Newspapers are quick to inform the public on what it costs the city for a grader, a tractor, or a truck. But how often does one read a report in the newspaper about how much it costs to maintain that unit or what it is worth at trade-in time? That does not make very interesting reading. This information can hardly compete for newsprint space with war news, crime and violence, or even the society page.

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TABLE 1

REPAIR COST SUMMARY OF MOTOR GRADERS

(Owned by a Midwestern State)

Type	Units	Average Age	Average Total Hours	Cost per Hour
A	15	15.7	14,008	$3.66
B	24	11.8	8,970	$4.64
C	7	11.9	8,405	$4.59
D	29	5.1	3,230	$4.87
E	44	3.9	2,555	$4.61

Perhaps the blame should be placed on the engineer in charge of preparing specifications. He should know how to write a spec that will insure purchase of the kind of machine he wants. He can; however, he is not designing the machine. He must write a spec that will allow the best possible choice of several machines already on the market. Therefore, he must rely on the data printed on manufacturers' specification sheets that say nothing about how long the unit will last or how much it will cost to operate.

How about considering the manufacturer in fixing the blame? Certainly, part of the problem originates with the manufacturer. It is a fact that some machines are "designed" to meet minimum specifications set by government agencies. These units are then built as economically as possible in order to minimize costs allowing the manufacturer's distributor to price his unit low in a competitive bid. In an effort to minimize costs, shortcuts are taken that show up in premature failure of certain components. But can all the blame be placed on the manufacturer? What incentive is there for him to build a better unit for which he must ask a higher price, if the government agency continues to buy on low bid?

Actually, most government officials know how to purchase in such a manner so as to avoid the problems discussed previously, but they are faced with a most perplexing dilemma. They can write tight specifications insuring the purchase of the specific machine they want. But they are likely to come under fire from several areas, primarily from the supplier who offers a product that almost meets the specs and may perform equally well as the one around which the specs were written. And what encouragement is there for the one supplier of the desired machine to make his price competitive? So to avoid criticism, specifications are sometimes relaxed, allowing all suppliers to meet the requirements. The results are not difficult to predict. The risk here is getting a unit that runs well, right up to the end of the warranty period, and then turns out to be one of the most expensive machines anyone ever had on his hands.

Many government agencies are making use of a relatively new purchasing concept to solve this dilemma. It is called "total cost bidding". The principle is quite simple. Equipment suppliers enter not only the bid price for the initial purchase, but guarantee—for a period of time (usually 5 years)—a maximum repair cost and a minimum repurchase price at the end of the stipulated period. These guarantees are backed by performance bonds to insure that all provisions of the contract will be fulfilled. The bid award is made on the basis of initial price plus repair cost minus repurchase price. The lowest net cost is then the best bid regardless of initial price. Figure 2 shows the bid form used in a typical total cost bid.

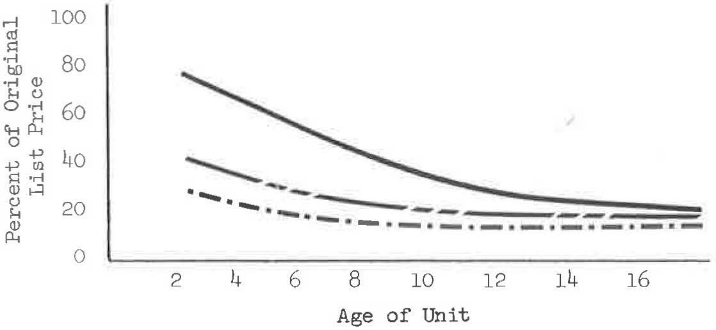

Figure 1. Used equipment auction values based on prices of machines sold at Forke Bros. auctions.

BID PRICE $______

\-

GUARANTEE REPURCHASE ______

DIFFERENCE ______

\+

GUARANTEE MAXIMUM REPAIRS ______

=

NET TOTAL COST BID [ ]

Figure 2. Total cost bid form.

The supplier is not responsible for repairs caused by accidental damage, sabotage, or abuse. Likewise, normally recurring maintenance items, such as fan belts, filters, tires, glass, and wire rope are not included in the maximum repair guarantee. In order to minimize downtime, total cost bid specifications can include a penalty for excessive delays in parts procurement. Repairs are performed by the agency or the equipment supplier. Accurate records are maintained and reviewed periodically by both parties.

The total cost concept is being utilized by governments at every level. Cities, townships, and counties in nearly every state have purchased equipment on this basis—and not only road maintenance equipment. The City of Chicago has purchased refuse trucks and is considering applying the concept to typewriters. Several state governments have used this bid method and others are studying the concept. In 1968, the State of Maine bought a wheel loader and 9 road graders on this basis. Bid results on some graders are given in Table 2.

Whereas the models purchased by Maine were priced second from low on initial price, they were low by a wide margin on a total cost bid basis. These bid figures correlate closely with actual cost records kept by the state. That is, records show a considerable variation in operating cost among the various makes. Florida recently purchased 7 loaders, 6 graders, and a tractor by total cost bid.

Some branches of the federal government are using the total cost concept in an effort to evaluate all costs at the time of purchase. The TVA purchased 28 crawler tractors; Ft. Hood, 2 crawler tractors; and Ft. Sill, 4 graders, all on this basis. Actually, the Pentagon has had the latitude for some time to award contracts on a basis other than initial price. In 1947, Congress enacted an armed services procurement law allowing that the "award shall be made . . . to the responsible bidder whose bid . . . will be most advantageous to the United States, price and other factors considered." The Pentagon has lately been considering these "other factors" in what it calls "life cycle costing".

TABLE 2

BID RESULTS FOR SIX MOTOR GRADERS

(State of Maine, July 1968)

Bid Items	A	B	C	D
Net price, 6 units	$120,000	$134,130	$106,000	$128,310
Repurchase guarantee, 5 years	75,000	72,000	No	No
Repair guarantee, 10,000 hours	7,500	17,880	No	No
Net total cost bid	$ 52,500	$ 80,010	No	No

Total cost bidding calls for some changes in purchasing policy on the part of some government agencies. It sometimes requires dogged persistence and superior courage on the part of public officials to use this bid system in the face of severe criticism from various sources—to stand firm in their attempt to determine all of the costs of owning and operating a piece of equipment before the purchase order is signed, not several years later when it is too late. But the rewards are very real. First, it allows comparison of the various units offered on an even, equitable basis—i.e., if the guarantee requirements are made mandatory. Just as the bidders are required to meet specifications regarding horsepower, weight, and mechanical features, in a total cost bid they should all be required to guarantee their machines.

With depreciation and repair costs known in advance, budgeting and planning for future equipment purchases are made easier. Through the use of total cost bidding, the time wasted while machines are waiting for repairs can be reduced because equipment is more available for work. It will undoubtedly cause some reduction in the size of equipment spreads owned and operated by government agencies, and the resulting savings can be spent on other projects.

Buying heavy equipment on low bid is risky and often results in wasting tax dollars, unless the low bid is a total cost bid, because the lowest total cost bid has to be the best bid offered. Many government agencies across the country are finding this out and taking advantage of this new bid system.

The reader may wonder why government agencies do not all immediately begin purchasing on this basis, if total cost bidding has so much to offer. Resistance to change is inevitable. Any time you ask someone to change the way he has been doing something for years you are likely to have an argument on your hands. Some of the objections to total cost bidding have come from government officials themselves, usually due to a lack of understanding or appreciation of what this bid system can do for them.

Most opposition has come from manufacturers and suppliers who have come to rely on low bid governmental business and have developed specific models to meet bare minimum specifications with major emphasis on low initial price. Continued use of total cost bidding will inevitably result in one of two courses of action on the part of these equipment manufacturers. They will either build better equipment that will incur fewer repairs or lower the price of their existing lines in order to compete more effectively on a net total cost basis. In either case, the government agency comes out ahead.

Regardless of the origin of these objections, it is important to be aware of them and to analyze each one objectively in order to fully appreciate the potential benefits available to government agencies through the use of this purchasing method. The following points have been raised:

1. "Total cost bidding is a gimmick designed to favor one supplier exclusively." The kinds and makes of equipment purchased on this basis disprove this theory. The repurchase guarantee is a unilateral agreement. The buyer at his option may (a) sell the machine back to the supplier at the end of the contract period under no obligation to purchase a similar unit; (b) keep the unit; (c) trade it in to another supplier; or (d) sell it at an auction possibly for more than the guaranteed repurchase price. He has complete flexibility in disposing of the unit with a base value established by the guarantee. In fact, total cost bidding insures awarding the bids on a more equitable basis than does initial price bidding. With all obligations on the part of the buyer and seller spelled out in the specifications, there is no chance for foul play or dodging responsibility. Total cost bidding does show favoritism, in that it favors the machine that will operate most economically. It also favors the supplier who can provide the best service at the least cost to the owner. Contractors buy equipment with one major factor in mind—profit. They know that the machine costing least to own and operate will give them the most profit. Government officials may not make buying decisions with a profit motive in mind, but the same considerations should apply whether trying to make a profit or save tax dollars.

2. "Total cost bidding results in higher prices paid for equipment." Usually this is true, if you are considering initial price only. But total cost bidding also considers repairs and depreciation, thereby resulting in substantial savings over the useful life of a machine. When it comes time to trade a machine purchased by total cost bidding, the initial price of the new unit will likely be less due to the higher resale value recovered from the repurchase guarantee on the first unit.

3. "There are too many loopholes in total cost bidding, allowing the supplier to escape from obligations made at the time of purchase." The performance bond insures the government agency that all provisions of the contract will be fulfilled. Specifications also include provisions for arbitration in case disagreements should arise over the responsibility for certain repairs.

4. "Total cost bidding is restrictive and eliminates competitive bidding." It does result in some risk on the part of the bidder but in no way restricts him from bidding. It merely requires bidders to state in advance the repair cost and resale value anticipated on their machines and back up these guarantees with performance bonds. A supplier who is unable to obtain performance bonds for use in total cost bidding may not be in a position to provide sustained good service and performance on this type of arrangement. In this way, total cost protects the government buyer from the supplier who is unable to back up his claims of superior machine performance at lowest cost. No one is in a better position than the bidder to anticipate these costs, especially where a new model is involved. In effect, total cost bidding forces each bidder to evaluate the quality of his machine in terms of dollars and cents.

At last government officials have found a purchasing method by which they can make a realistic comparison and award the bid on the basis of something more than initial price alone. More important, they can justify their actions and prove to the public that their decision to spend more initially will produce significant savings in the long run. Total cost bidding is now well established as a purchasing method. Just how widespread it becomes will depend largely on the courage of public officials to risk a little criticism in order to do a better job of purchasing equipment.

Discussion

IRA F. DOOM, Virginia Highway Research Council—The paper may be assessed in terms of two general subject areas: (a) a theoretical reaction to the paper assuming no experience with total cost purchasing; and (b) some observations based on Virginia's experience in applying some of the concepts mentioned to the acquisition of motor graders.

An initial reaction to the paper is that the basic concept of total cost purchasing for both private and public agencies is inarguable; i.e., there is more to the cost of equipment than initial price. From a conceptual point of view, total cost bidding is a method of purchasing (or selling) that will result in mutual benefits for the quality producer and the purchaser or user.

The author is to be complimented in that he has made a real effort to define the elements in total cost bidding. Specifically, he has mentioned initial price, parts costs, downtime, resale value, and labor costs. I would, however, like to comment on some aspects of the paper in light of attempts at practical application to state purchasing. Specifically, (a) in defining total costs the interest factor should be taken into account; and (b) total cost purchasing does not necessarily require awarding of the bid to the supplier that offers the lowest total guaranteed cost, because true total cost purchasing or bidding necessitates an evaluation of alternative methods of purchase (projected total costs of an award on the basis of lowest initial bid price vs lowest guaranteed total costs).

Before a public or private agency can state that it is purchasing on the basis of lowest total costs, it must ascertain its overall costs under its current method of purchase—presumably lowest initial bid price. Confusion in this regard may be cleared up by relating Virginia's experience in total cost purchasing of motor graders. The Virginia Department of Highways was concerned that the lowest bid price was not the lowest overall total cost (Mr. Hughart's point), particularly since it had applied this principle to tires and saved $150,000 per year over the initial price method. The Department of Highways therefore specified in its bid forms that the award for graders would be based

TABLE 3

BIDDER A
COMPARISON OF LOWEST GUARANTEED TOTAL COST BID
INCLUDING AND EXCLUDING INTEREST

Item	Total Guaranteed Cost Including Interest	Total Guaranteed Cost Excluding Interest
Initial price	$26,448.00	$26,448.00
+	+	+
Interest compounded at 4 percent ($216 per $1000)	$5,712.77	$0
+	+	+
Guaranteed maximum parts cost	$700.00	$700.00
=	=	=
Total initial price	$32,860.77	$27,148.00
-	-	-
Guaranteed repurchase price at 5 years or 6350 hours, whichever comes first	$19,042.00	$19,042.00
=	=	=
Net bid price	$13,818.77	$8,106.00
÷	÷	÷
Hours used, 5-year period	6,350	6,350
=	=	=
Net costs per hour	$2.1761	$1.2765

on the bid that would result in the lowest overall total cost in the Commonwealth. Without discussing in detail Tables 3, 4, and 5, a summary analysis of these tables shows that consideration of interest did indeed make the difference in practice in terms of which method of purchase resulted in the lowest overall total cost to the Commonwealth and also with reference to actual costs per hour.

Succinctly, the lowest guaranteed total cost bid submitted to Virginia (bidder A) was $2.18 per hour vs the projected costs of the initial price bid of $1.88 per hour. In other

TABLE 4

BIDDER B
COMPARISON OF PROJECTED TOTAL COSTS OF LOWEST INITIAL PRICE BID
INCLUDING AND EXCLUDING INTEREST

Item	Projected Initial Price Bid Including Interest	Projected Initial Price Bid Excluding Interest
Initial price bid	$14,591.00	$14,591.00
+	+	+
Interest compounded at 4 percent ($480 per $1000)	$7,003.68	$0
+	+	+
Estimated parts cost (28 cents an hour for 12,700 hours)	$3,556.00	$3,556.00
=	=	=
Total initial costs	$25,150.68	$18,147.00
-	-	-
Estimated resale value at end of 10 years (9 percent of initial price)	$1,313.19	$1,313.19
=	=	=
Net total cost	$23,837.49	$16,833.81
÷	÷	÷
Hours used over 10 years	12,700	12,700
=	=	=
Net costs per hour	$1.8770	$1.3254

TABLE 5

BIDDERS A AND B
COMPARISON OF COSTS PER HOUR UNDER ALTERNATIVE METHODS OF PURCHASE
INCLUDING AND EXCLUDING INTEREST

Total Guaranteed Costs Per Hour Excluding Interest	Projected Initial Price Bid Costs Per Hour Excluding Interest	Total Guaranteed Costs Per Hour Including Interest	Projected Initial Price Bid Costs Per Hour Including Interest
$1.2765	$1.3254	$2.1761	$1.8770

words, in this case, based on 12,700 hours of use of 15 graders (the number purchased), Virginia saved over $50,000 by not using the lowest guaranteed total cost.

More important, however, is that if interest was not used in the purchase evaluation, bidder A's bid would have been considered to be $1.28 per hour vs $1.33 per hour projected from the initial price bid. In practice then the total cost bidding method proposed by Mr. Hughart would have resulted in a fictitiously low statement of costs and an improper management decision.

I think that in view of Virginia's experience other agencies and managers should note the following in consideration of total cost bidding:

1. Know the costs of operation under the current method of purchase;
2. Include interest in the calculations;
3. Compare results of alternative methods of purchase; and
4. Do not accept "total cost" formulas until their implications have been thoroughly evaluated.

I feel that Mr. Hughart has made a commendable effort to upgrade the quality of purchasing decisions of public agencies. This effort has understandably emphasized the seller's side of the ledger and in the interests of the taxpayers the method should be seriously modified before it is put into practice.

In summary, I do not mean to oppose the use of total cost bidding (as a matter of fact I am all for it), but I do not think it should be used until a detailed analysis of costs and interests of suppliers has been conducted by the purchaser in question. I have tried to be helpful to that end.

W. M. HUGHART, Closure—The State of Virginia and Mr. Doom are to be congratulated on the thoroughness of their evaluation of total cost bidding. Including the factor of investment cost is an important refinement of the total cost bidding procedure, especially where bids show a wide differential in initial price.

The bids received by Virginia emphasize a most important consideration in the use of total cost bidding by government agencies. Unless the guarantee requirements are made mandatory, comparison of the bids on an equitable basis may be difficult if too few total cost bids are received. Any attempt to compare a total cost bid with a conventional low initial price bid must involve certain assumptions regarding anticipated repairs and resale value. Evaluating a low initial price bid that includes assumptions against a total cost bid that includes specific cost guarantees may penalize the latter and thus rob the government agency of the real benefits that accrue from this bid system.

Total cost bidding places all bidders on the same basis with respect to proving the true value of the machines they offer for sale. The real benefit of this bid system is that it enables government agencies to compare the true value of different machines at the time of purchase rather than leaving it up to experience, which may prove costly.

Data Structure for a Construction Company Management System

A. P. FROEMMING and S. J. FENVES, University of Illinois

The object of this paper is to outline a data structure framework that would make possible the integration of the various data involved in data processing into a management information system for a construction company. The scope of consideration of a construction company system is limited to the four basic operations of accounting, payroll, CPM, and estimating. CPM is envisaged as both an updating and monitoring tool for the actual construction operations, as well as a planning and scheduling tool.

The data structures in the four operations are described with emphasis on the hierarchical arrangement of the data. The interaction between the data structures on a company-wide basis is discussed in terms of the company activities of bidding and pre-project planning, project control, and generation of historical data.

The data structure presented deals only with the format of the data, and does not depend in any way on the contents of the data. The value of the system to the user depends exclusively on his ability to formulate his particular requirements within the context of the structure.

•ONE problem confronting management of a construction company is the ability to integrate easily the various elements of data that constitutes a construction company system. For example, the data resulting from the most commonly used estimating procedures are not convenient to use in keeping cost records on a project. Similarly, the normal accounting systems have no convenient way of associating the various project expenses with individual project cost accounts.

The object of this paper is to outline a data structure framework that would make possible integration of the various data elements and supply the desired management information. The scope of consideration will be limited to the four basic operations of a construction company system: accounting, payroll, CPM, and estimating. Figure 1 is a simplified representation of a construction company data processing and management system, showing the four operations and the existing data paths between the four operations, as well as the data going in and out of the management system. The functions of accounting, payroll, and estimating are straightforward. In this paper, CPM is considered as both an updating and monitoring tool for the actual construction operations, as well as a planning and scheduling tool.

DATA STRUCTURE OF OPERATIONS

In this section, the data structures involved in the four basic operations are described, with emphasis on the hierarchical arrangement of the data and on their interrelationship within each operation.

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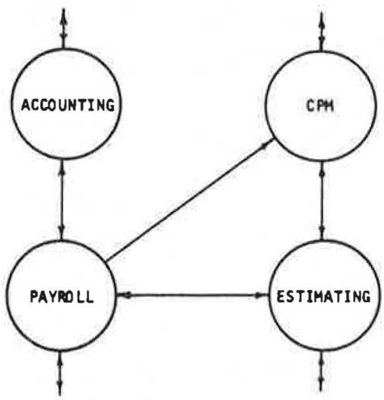

Figure 1. General layout of operations.

Accounting

The hierarchy of the data structure within accounting involves three levels of data: statement entries, open accounts, and account entries. The collection of statement entries forms either the balance sheet or the profit or loss sheet for the company.

The data structure within accounting is shown in Figure 2. Here, as well as in all remaining figures in this section, the data structure is represented in a skeleton form. The columns represent data at various levels of the hierarchy. In each column, one or more typical data items are shown, separated by double lines. Arrows are used to show the interaction between the data at the several levels, either as a cross reference or as an actual transfer of data. The three types of data will be discussed in turn.

1. Statement entries consist of an identification code (ID) for the line of the statement and the line of the statement itself. The following is an example of entries that might be made in a balance sheet:

DESC1	BALANCE SHEET
DESC2	CURRENT ASSETS
100	CASH WEST SIDE BANK
101	ACCOUNTS RECEIVABLE
SUB1	SUBTOTAL CURRENT ASSETS
200	ACCOUNTS PAYABLE
400	JOB MATERIAL EXPENSE

The line ID has two purposes: internal referencing within the statement, i.e., to let the user identify a line that he may wish to change or delete, or following which he may wish to insert a new line; and upward referencing from the open accounts, i.e., to associate the various accounts with the proper line of the financial statement. The line

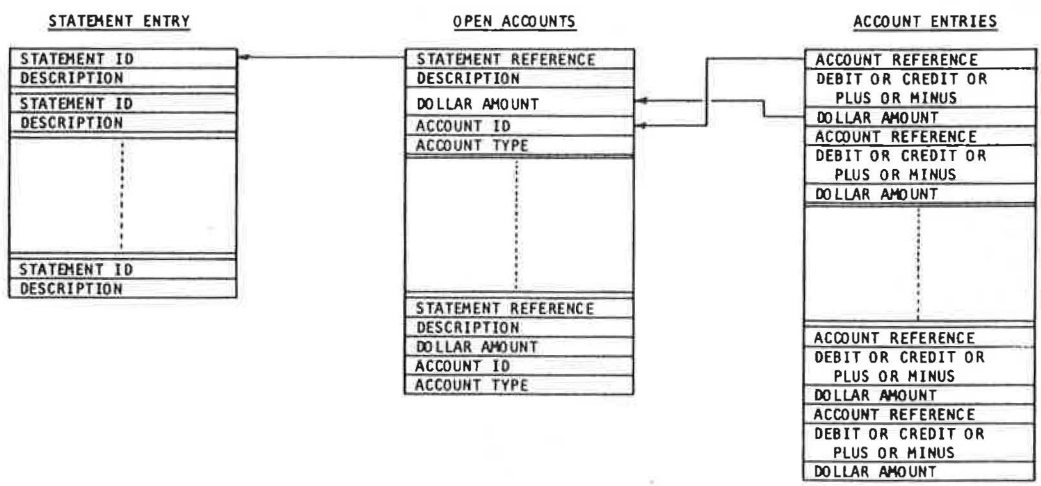

Figure 2. Accounting—the general case.

of the statement itself consists of optional descriptive text, except that the first word of the description may be one of the reserved words "surplus", "profit", "total", or "subtotal". The function of these words is to indicate where the totaling calculations are to be performed and printed.

2. Open accounts consists of (a) a statement of reference, i.e., the ID of a statement line; (b) dollar amount in the account at the time it is opened; (c) ID of the account; and (d) account type.

The account type designates the account as being one of the following: asset, liability, expense, income, account receivable, account payable, or fixed asset. The account type is used in the preparation of the financial statement as well as to check the validity of account entries referencing the account.

The data for an expense account differ from those of other accounts in that, in addition to the actual dollar amount, values of estimated material quantity, actual material quantity used, and budgeted dollar amount may be associated with the account. In addition, a project reference may be included, referring to a particular set of cost accounts in the payroll program. These additional data are of importance both as current information to the user and for the interaction of accounting with payroll and ultimately with the estimating program.

With any expense account it is possible to associate an auxiliary account. More than one expense account may reference the same auxiliary account. The use of the auxiliary account is discussed later. Figure 3 shows the layout of the data in an expense account. The following are examples of data for open accounts:

```
100  $8,000.00 A100 ASSET
101  $1,568.39 AR100 ACCOUNT RECEIVABLE
200  $6,247.00 AP100 ACCOUNT PAYABLE
400  EXP100 EXPENSE BUDGET $35,000.00 QUANTITY 255 JOB-10 AUX10
```

In the last example a new account is being opened. No dollar amount exists in the account; $35,000.00 is the budgeted amount; 255 is the estimated material quantity; JOB-10 references a project ID; and AUX10 is the ID for the auxiliary account.

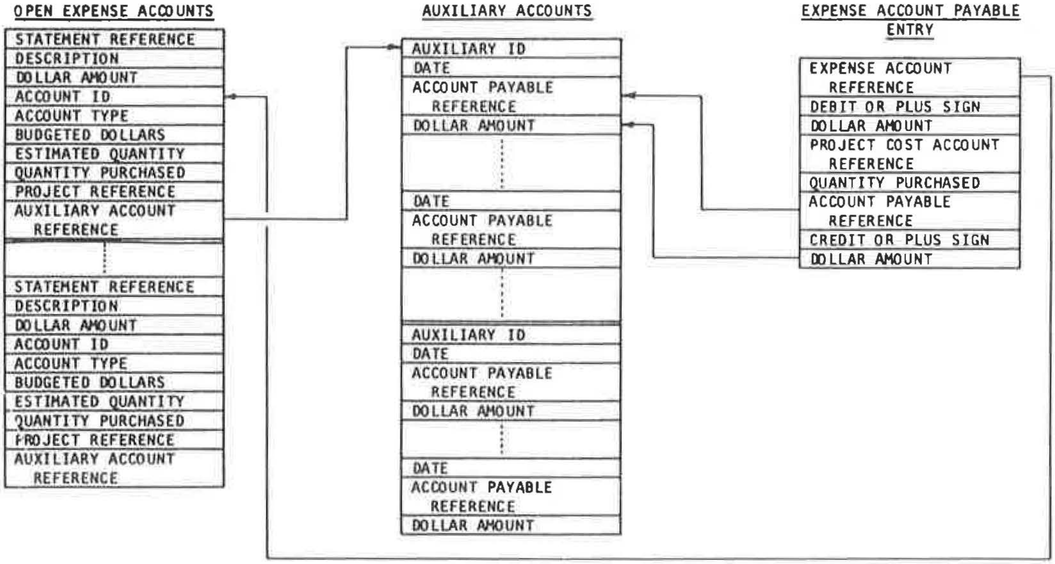

Figure 3. Accounting—the expense and auxiliary account.

3. Account entries consist of a minimum of two sets of data, each with an account reference, the label DR (debit) or CR (credit), and a dollar amount. A plus or minus sign may be used in place of DR or CR. The formula used to determine whether the entry is in balance is Assets = Liabilities + Net Worth + Income - Expense. An example of an account entry is as follows:

A100 DR $1,568.34

AR101 CR $1,568.34

or, using signs,

A100 + $1,568.34

AR101 - $1,568.34

An expense accounts payable entry could look as follows:

EXP100 + $5,000.00 CON684 QUANTITY 2400

AP100 + $4,000.00

In the preceding, CON684 is a project cost account reference and 2400 is the quantity purchased. Since the expense account EXP100 is associated with auxiliary account AUX10 (see last example above for open accounts), the account payable reference and the dollar amount, together with the date of the entry, are stored in the auxiliary account, i.e.,

7/28/68 AP100 $4,000.00

If all the expense accounts for a given project were associated with the same auxiliary account, the balance in that auxiliary account would always represent the total amount of moneys owed on the project. By referencing the data in the auxiliary account, it is possible to write checks to the vendors for a given project and thereby simultaneously reduce cash, accounts payable, and the auxiliary account by the amount of the check.

Payroll

The data used in payroll fall into three main categories: entries made on projects in progress, temporary data for a pay period, and permanent data. The permanent data can be further divided into two main categories: (a) data on the individual man; and (b) data pertaining to the individual cost account on a project.

The data on an individual man (Fig. 4) consists of ID; name and address; social security number; number of dependents; a craft type identifier (i.e., carpenter, laborer, iron worker, etc.); and earning and deduction data, consisting of gross yearly earnings, yearly federal tax, yearly FICA, etc., and quarterly earnings and deductions.

The collection of data pertaining to the men on the company's payroll constitutes the man file. It is to be noted that whereas the ID, name, address, etc., for a man are entered directly into the man file, the earning and deduction data are accumulated as a result of payroll processing.

The data for a typical cost account on a given project are an ID for the account, account description, estimated quantity needed, estimated cost of material, estimated dollars for labor, real quantity purchased, real dollars spent on material, real quantity installed, real labor dollars spent, and number of total hours worked on the account per craft type. The collection of cost accounts constitutes the cost account file. The initial entries (estimates) are entered at the time the project is started, and the remaining entries are accumulated as the project progresses. For report-generating purposes, cost account entries containing the words "subtotal" or "total" in the description may also be defined.

Conceptually, the data processing involved in payroll is merely to accept and check field report data, generate the temporary data (check register) for the pay period, and produce various derived reports. Again referring to Figure 4, the field report data

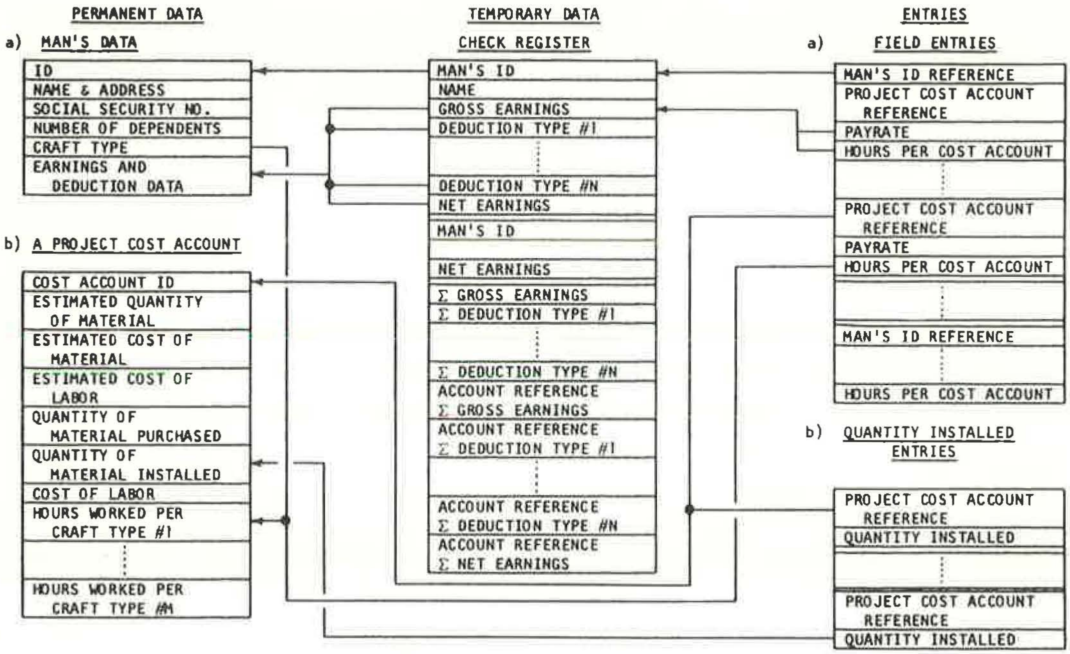

Figure 4. Payroll data structure.

are made up of the man's ID reference, a cost account reference, a pay rate, and number of hours worked on the given account at the stated pay rate. As many sets of account-rate-hours as needed to describe the man's activities may be entered for any given period.

The checks for payroll may be written on the basis of the field data and the man data (Fig.4), and the man data and cost accounts updated accordingly. The check register, together with the permanent data references, also contains all the information necessary to prepare government reports, union reports, and insurance reports.

The input of quantity installed for each account active during the period completes the data processing necessary to update the cost accounts. By entering the ID's of various pieces of equipment instead of men, this same system can be used to charge a project cost account with equipment rental expenses, using the rental rate of the equipment where the man's pay rate is used. The ID of the equipment would indicate to the system that no check should be written and that the data should not be used in union, government, or other similar reports.

Estimating

The data needed for estimating consists of three levels of hierarchy: the production history, estimate items, and estimate data (Fig. 5). The three types of data will be discussed in turn.

1. Production history consists of two types of data: descriptors and individual records. The intent of the descriptors is to provide the most flexible means possible to retrieve from production history data relevant to a new project being estimated. These data are transferred to the estimate for review by the person pricing the project. For generality, a three-level hierarchy of descriptors is considered.

The first and second levels of description for a new project need be input only once, when the estimating process is started. The first level of descriptors would narrow the search to only those production histories that have the same first level descriptors as the one entered. The second level descriptors would further decrease the area of search.

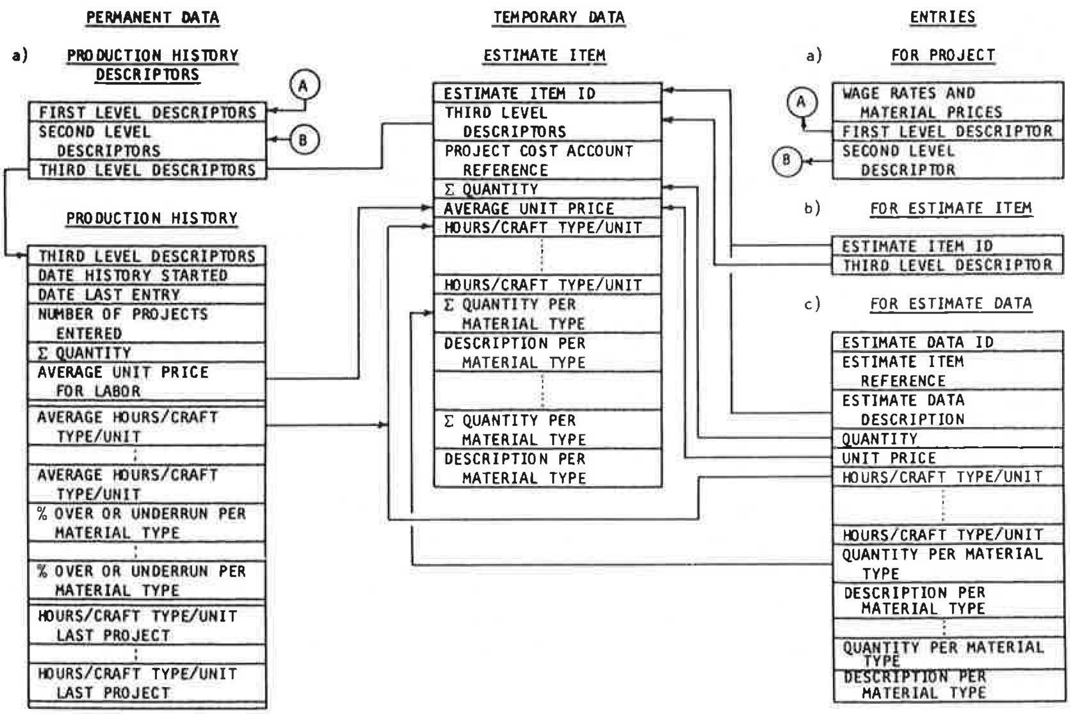

Figure 5. Estimating.

Third level descriptors would be entered for each estimate item on the new project. The third level search is limited to only those histories that have had a match on the first and second level. The third level of description of a production history record must match the descriptors of each estimate item. Examples of possible descriptors would be

Level #1	SOUTHWEST ILL GRADING NORTHEAST WIS GRADE AND PAVE
Level #2	100,000-200,000 CY 20-30% ROCK EXCAV 800,000-1,000,000 CY 10-15% SAND
Level #3	10,000-12,000 CY ROCK RIPPER WASTE 3-4 MI. +3% GR 8,000 CY CLAY 2,000-2,500 FT. HAUL -2% GR. 95% COMP.

The production history record referenced by the descriptors consists of the date the history was started; date the last data were entered into this record; total number of projects making up the data in record; a summation of the quantity of the item installed; average unit price for labor; average hours worked per craft type per unit; and percent overrun or underrun of material estimated as opposed to material purchased.

The data for the last project that was entered into the production history record are also stored separately (Fig. 5).

2. Estimate items comprise a file created as the particular project is being estimated and which remains in existence as long as the project runs. If the company was not awarded the project, the estimate item file for the project would be removed. The estimate item contains information such as estimate ID, third level descriptor, cost account reference (may be filled in later if the company was awarded the contract), summation of estimated quantities, average unit price, hours per craft type per unit, summation of the quantity of various types of material estimated, description of the

material, date of the last job, date the production history was started, and number of jobs that are included in the production history.

If a matching production history record exists, the minimum input necessary is an estimate item reference and the quantities of the various material types. This minimum input is valid only if the summation of quantities is equal to one (i.e., if the production history record refers to a single entity), in which case the data on hours per craft type per unit is transferred to the estimate item, together with the summation of the products of wage rate per craft type times hours per craft type. This summation would appear as the average unit price. The estimated summation quantity per material type would be increased or decreased as indicated by the percentage overrun or underrun from the production history.

The other case where production history would be used is where only quantity and material type are entered into the estimate data along with the estimate item ID. In this case, at the user's option, either the average unit price or the average hours per craft per unit from the production history would be used in the estimate item. The material would be treated as described previously.

Unlike in accounting and payroll, the data on the first level of hierarchy, i.e., the production history, need not exist in order to operate at the second level, i.e., the estimate item. If the production history does exist, it will be accessed by the proper estimate item; if not, a new production history would be created after all the data from a given project were available from the project's cost account file.

3. Estimate data consist of the information that a takeoff man normally assembles. The input (Fig. 5) consists of ID for the estimate data, estimate item reference, estimate data description, quantity of this estimate data, unit price for labor, hours per craft type per unit, quantity of material type No. 1, and description of material type No. 1. There may be several sets of material data for any given estimate data ID. Any information that is supplied to an estimate item by the input of estimate data would override the corresponding data that would normally be retrieved from the production history.

Regardless of the type of data processing employed, the estimating process begins by the takeoff man assigning an ID to each estimate data on the project summary sheet, and then giving the same estimate item ID to all summary sheet estimate data that he wishes to group together.

A meaningful way to utilize the data structure described would be to enter in the estimate item the third-level descriptors described. This would allow for a recall of the relevant information from the production history. The wage rates and material prices would be entered before the estimate items are specified. From these data, plus the production history, the cost of each estimate item would be calculated. The estimator could then review the resulting calculated cost. If the cost was satisfactory to him, he would approve it. If the cost did not meet with his approval, he would make the necessary modifications and reenter the modified estimate item data. After he has satisfied himself concerning each estimate item, the recap sheet and total estimate could be prepared.

A further step in exploiting the available data structure would be to associate cost account references with the estimate item. In this way, it would be possible to obtain from the cost accounts the hours per craft type per unit for the production history; such information could then be retrieved and used in preparing future bids. For example, a third-level descriptor in production history may be:

48" MANHOLE BLOCK 10'-12' 24" CORBEL

Upon completion of a project, data from cost accounts referenced by estimate items having this descriptor would be transferred into the appropriate production history record. When the same descriptor is used for an estimate item on a new project, the user would have to enter only the actual material quantity for the particular manhole. The data returned from production history would be the hours per craft type for that entity. In this fashion, on the assumption that production costs do not vary for similar items where the material quantities vary within certain limits, labor costs on classes of similar items can be treated for estimating purposes as a single entity.

CPM Planning

The data for CPM planning consist of information or individual operations of a project or network and derived quantities obtained from processing the network. The data for a single operation of a CPM network (Fig. 6) consist of operation ID; estimate reference (could be used as the operation ID); cost account reference (could be used as the operation ID); operation description; operation duration; cost of the operation; operations immediately following the given operation; resource types and quantity, e.g., crew size and composition and/or equipment requirements; earliest start target date; earliest finish target date; latest start target date; latest finish target date; number of shifts worked on the operation; and indicator if work will take place on Saturday, Sunday, or holidays.

The minimum information that is required for an operation in order for the network calculations to take place is (a) one of the three possible operation ID's; (b) operation duration; and (c) operations immediately following the given operation. The start date of the project would be entered for calendar dating purposes.

From this information, the CPM calculation can supply the earliest start time, latest start time, earliest finish time, latest finish time, and the total and free float for each operation.

Three files on CPM operations can come into existence as a result of processing a given CPM network (Fig. 6). Two of these files are of a permanent nature, while the third is temporary and is used only for trial-and-error work in an effort to get the best schedule possible. The original network data, generated at the time the project is initiated, are stored in the base network data file. Experimentation or simulation with the network may be performed at any time. If it is desired to save the data entered to modify the network, information on the affected operations is stored in the network update file, but the base network file remains unchanged. The temporary data pertaining to trial network modifications exist only temporarily in the network modification file. In CPM, as in the payroll system, equipment may be treated in the same manner as labor.

INTERACTION OF DATA STRUCTURE

In this section the interaction of the data structures of the individual operations on a company-wide basis is discussed. The interaction is described separately in terms of

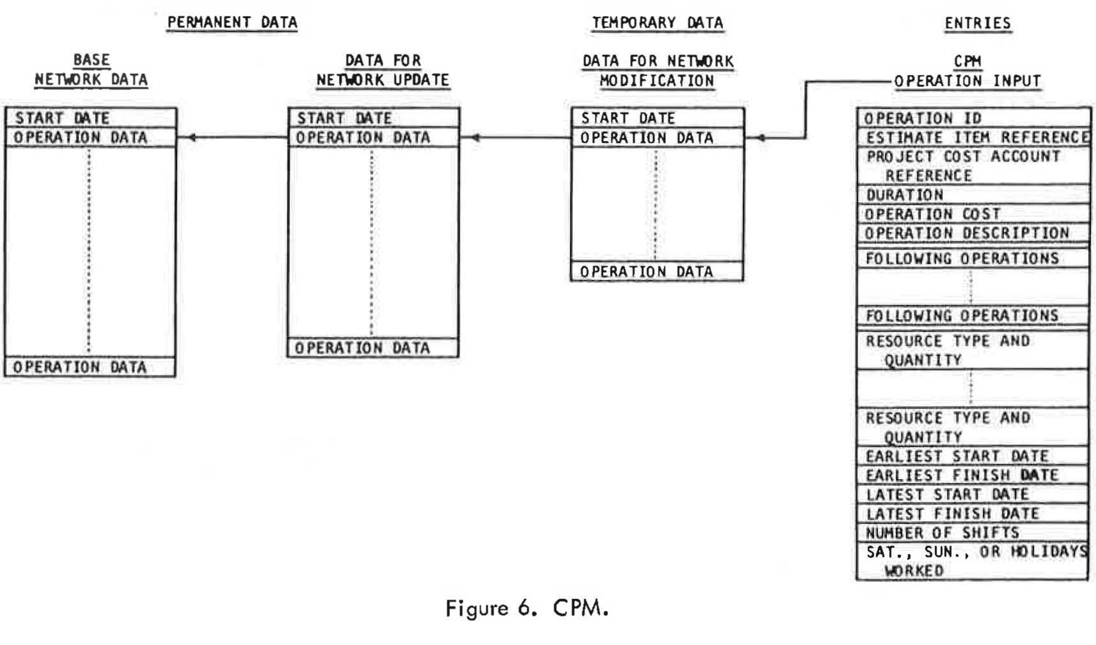

Figure 6. CPM.

the three major activities associated with a given project, namely, bidding and pre-project planning, project control, and generation of historical records.

Bidding and Pre-Project Planning

The initial steps in setting up a project are (a) to prepare an estimate; (b) to set up the project cost accounts; and (c) to obtain an initial CPM network.

The process of estimating was discussed previously. It should be remembered that in preparing an estimate, the pay rate for the various crafts, the material prices, the project overhead cost per day, and the first- and second-level descriptors (referring to the entire project) are initially entered for the entire project.

By associating a project cost account with each estimate item, the output of the estimating process (i. e., estimated material quantity and labor requirement) becomes directly the initial data of the project cost account.

The data for the estimated quantity of material in the project cost account can be transferred directly from the summation of quantity data of the estimate item that references it. The estimated cost of material would be the summation of quantity of the estimate item multiplied by the proper material price. More than one type of material may be involved in a given project cost account.

The estimated cost of labor may be arrived at either from the product of quantity times average unit price or the product of summation quantity times hours/craft type/unit times pay rate/craft type. From the same data, the estimated unit price and cost data are also available to the project cost account.

Figure 7 shows the transfer of information from the estimate and production history data. In this and succeeding figures in this section, only the project cost account data are shown in their entirety. For all other types or data, only the actual items directly interrelated are shown.

Since an operation on the CPM network may reference both a project cost account and an estimate item, the project planner need only supply the operation duration as

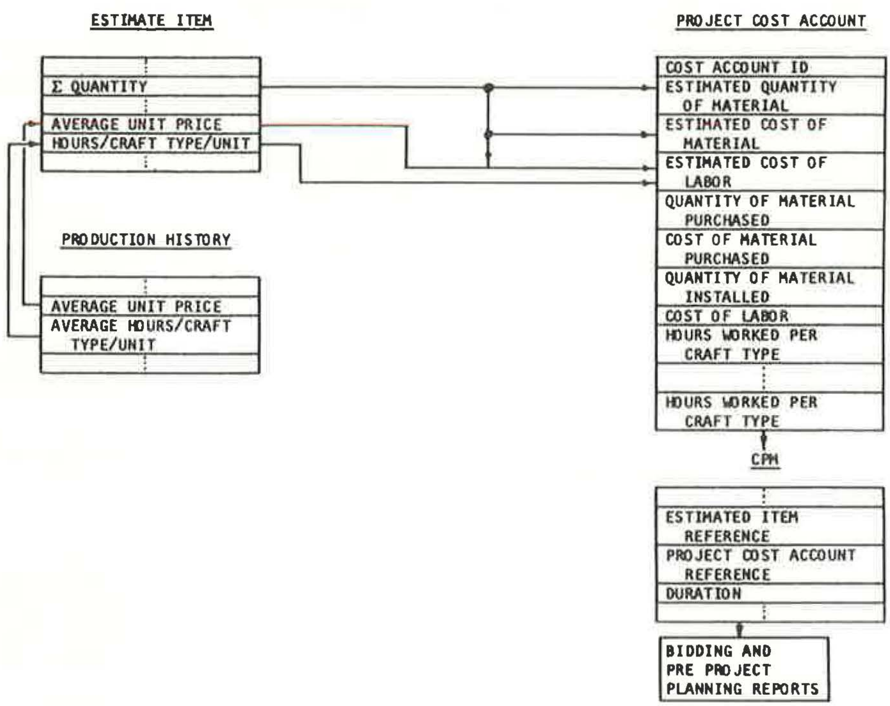

Figure 7. Bidding and project planning.

input for the initial CPM network. The initial contents of the cost account referenced by the operation already contain the labor cost, the material requirement, the material cost, and the manpower resource requirements for the operation from the referenced estimate item. This completes all the information on the operation necessary to run the initial (base) CPM network calculations. In fact, with the manpower resources available, the CPM program can calculate the operation durations directly.

The output of the initial network processing can supply the CPM results described, as well as the total dollar requirement for the project through each operation. The CPM duration multiplied by the project overhead cost per day may be used to calculate total project overhead cost.

In-Progress Project Control

In-progress project control makes simultaneous use of data from accounting, payroll, and CPM (Fig. 8). The data processing for in-progress control is essentially of two types: (a) progress reporting, accomplished by updating of the project cost accounts; and (b) control proper, which involves the preparation of reports directing changes to be made in the conduct of the project.

The updating of project cost accounts is accomplished as follows. The quantity of material purchased for a project cost account and the cost of that material are obtained from expense account entries of the accounting system. The information for material installed is a result of the quantity report input data. The labor cost for a project cost account is calculated by multiplying the hours worked per cost account from field report entries times the appropriate craft pay rate. Hours worked per craft type per unit for a project cost account come directly from the payroll system field report entries. An additional interaction of payroll and accounting in the in-progress phase is the transfer of the payroll cost information to the proper accounts in the accounting system, i.e., to reduce the cash account by the value of the net payroll or increase an account payable by the value of a deduction type.

For control purposes the system has available, through the CPM operations referencing project cost accounts, the data needed to update all CPM operations with regard

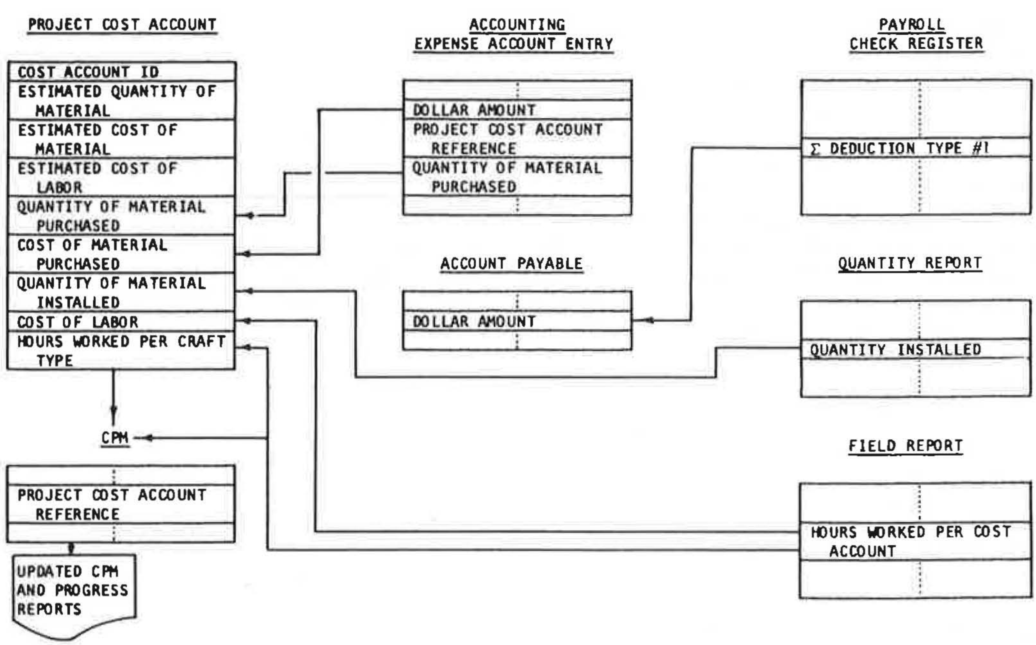

Figure 8. In progress project control.

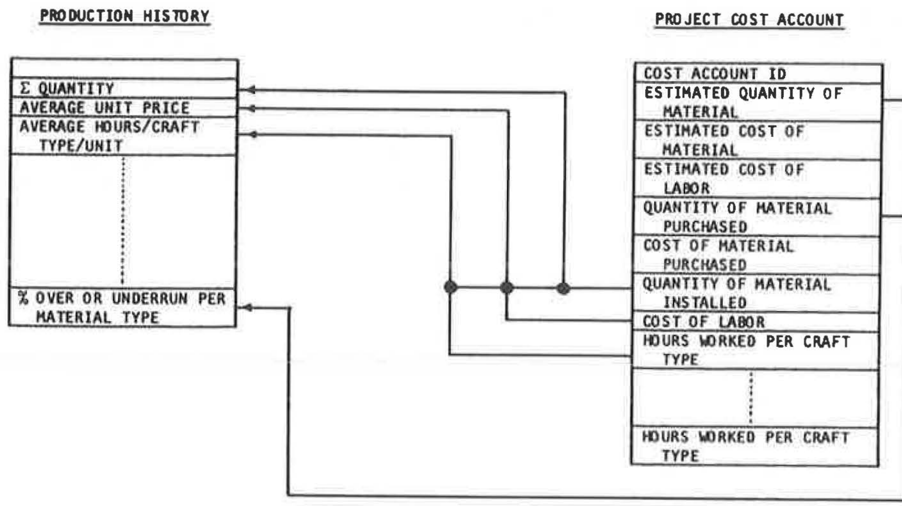

Figure 9. Generation of historical record.

to duration and cost. These data include (a) material yet to be installed; (b) rates at which installation has been occurring; and (c) size of the crew presently working (obtained directly from the field report entries).

The data on operations to be modified would be stored in the network modification file. The user can inspect this file or ask to run a new CPM network calculation. Should the automatic update data meet with the user's approval, it can be saved by transferring the data to the network update file. If not, the user can make any additional modifications necessary before accepting the results and transferring the data to the network update file.

Generation of Historical Record

At the successful completion of a project, information on the project may be transferred into the historical record. The generation of historical records involves interaction of only two parts of the system, payroll and estimating.

As described, a project cost account can receive its initial data directly from an estimate item that, in turn, received its data from production history. In the generation of historical records the data flow is reversed and goes from the project cost account into the production history (Fig. 9).

The summation of quantity in the production history record is a direct transfer from quantity of material installed. The average unit price for production history is arrived at by dividing the labor cost by the quantity installed, both taken from the project cost account, and then averaging it into the data of the production history record. The hours worked per craft type involve a direct transfer and computation of the average. The last item of production history, percent overrun or underrun per material type, is obtained as the quantity purchased divided by the quantity estimated and then averaged into the production history for each type of material.

In preparing the production history, the user would specify whether he wanted to operate with unit prices or if the production history is to maintain the summation of quantity equal to one, i.e., deal with separate entities. In the latter case, quantity of material installed from the cost account is used to calculate only the percent overrun or underrun per material type in the history record.

In the case where summation of quantity is kept in the production history, it would refer to the first material type listed in the project cost account. There are cases where this may be a dummy entry, such as square feet of forms. The remaining material types could then be wall ties, plywood, 2 × 4's, etc. In this way, the average unit labor cost, as well as the average hours worked per craft per unit, would be available from production history in terms of one type of material, i.e., forms in the example given.

SUMMARY AND CONCLUSIONS

A construction company data processing and management system consists of three main data sources:

1. Accounting—which is made up of two parts, the financial statements and the supporting accounts.
2. Payroll—where two data files are utilized, one for the data on the employees and one for the project cost accounts.
3. Estimating—where one part of the data, the production history files, can be used in aiding in preparation of the estimate. The other part of the data, the detailed project estimate, is used for pricing and buying the job.

Interaction of data takes place within each of the three parts. However, a much more important aspect is the interaction that occurs between the three parts and makes up the total construction management system.

The CPM network representation of a project, in conjunction with the project cost accounts, crosses the lines of all of the three main parts of the system, with the project cost accounts acting as the central data repository and CPM taking on the role of an interpreter of this data. The result of this combined action of CPM with the project cost report provides management with a simulation tool by enabling them to modify the network and interpret the effects of the modifications on the project under consideration. This combination also gives management a project control tool by reporting on current conditions of the company's projects and predicting the outcome of these projects. The automatic update of the CPM also can suggest changes in operating procedure that management may wish to implement.

The last task performed on a project is the storing away of the pertinent data for future reference. This information comes from the project cost accounts of completed projects and feeds back into the estimate of new projects.

It can be concluded that with the data structure described, a management system that would be of considerable help to a construction company could be implemented. It is to be emphasized that the data structure presented in this study deals only with the format of the data, and does not depend in any way on the contents of the data. The assignment of contents, i.e., the identification of cost accounts, descriptors, estimate items, accounts, etc., is entirely up to the user and can in fact resemble quite closely present practice. It also follows, however, that the value of the system to the user depends exclusively on his ability to formulate his particular requirements within the context of the structure presented.

A common complaint about large-scale integrated systems is that they require a considerable amount of additional information to identify the interrelationships involved. It is believed that in the structure presented, these additional data are an absolute minimum, in that only one level of referencing is required at any point. Furthermore, in some cases even this can be omitted, e.g., by assigning identical ID's to estimate items, CPM operations, and project cost accounts.

It is obvious that much work remains to be done before the total system outlined in this study could be brought into existence. With the idea of the total system operating in an on-line conversational mode, careful consideration will have to be given to the physical structure of the data files involved. However, the existence at the present of on-line payroll (1), accounting (2), and CPM (3, 4) programs incorporating many of the concepts described, even though operating independently, attests to the fact that the implementation of the system is feasible.

Several extensions of the system presented are possible. In particular, the usefulness of the production history can be increased in at least two ways. First, by storing the variance as well as the averages of all the data listed in the production history record, these data could be used for PERT-type calculations on project durations, manpower requirements, and costs. Second, the production history may contain CPM subnetworks associated with third-level descriptors. Whenever a CPM operation references an estimate item that fits an existing third-level descriptor, the corresponding CPM subnetwork could be retrieved and automatically linked into the project network.

ACKNOWLEDGMENTS

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Information Needs for Controlling Equipment Costs

ELMER A. COX, Construction Services Manager, H. B. Zachry Company

> Facts are to the mind what food is to the body . . . The wisest in counsel, the ablest in debate, and the most agreeable companion in the commerce of human life is that man who has assimilated to his understanding the greatest number of facts.
>
> —Edmund Burke

•IN the construction industry, no subject has appeared more controversial and no facts more illusive than those pertaining to equipment costs. Aside from the basic difference from other costs, in that expenditures for equipment occur long before use, confusion stems from an inherent variability in the type and amount of work put out for bids, suitability of owned equipment for future work, inflation, tax considerations, and measuring and reporting problems. To illustrate the need for more reliable information, Figure 1 shows financial ratios for different categories of contractors. The ratios show profit after taxes to net worth and also profit to volume, and illustrate the difference in risk between categories of construction work. The comparison of the amount of variation between heavy and highway construction and the other categories of construction requiring less equipment is quite striking. The difference is primarily the ratio of equipment to labor, and the figures show quite clearly our inability to predict our equipment needs and control our equipment costs under present bidding practice and environmental conditions.

Figure 2 shows the spread of bids for highway work in Southwest Texas. The discrete curve represents the distribution of the sample of 56 bids and the smooth continuous curve is the normal curve that fits the observed data. The sample passes the chi-squared test for goodness of fit at a significance level of 0.05; we may therefore accept the hypothesis that the bids were normally distributed. One standard deviation is equal to 10.28 percent and, therefore, a 40 percent range is required to account for 95 percent of the bids submitted. No attempt was made to identify the variables producing this range of variation. The author contends that the most significant factor is the condition under which we attempt to manage our equipment investment. Weather is not as significant a factor in Southwest Texas as in other parts of the country, yet it can affect costs considerably.

A last example of the variation in cost is taken from the equipment files of H. B. Zachry Company. Figure 3 shows the amount of variation in equipment costs that may be attributed to differences in job conditions. The two 660 scrapers in Figure 3 were purchased at the same time and worked under similar conditions for the first 6,000 hours. At that time equipment number 770708 was assigned to a job in the Franklin Mountains near El Paso and number 770707 stayed with a spread at a dam near San Antonio. The maintenance costs incurred after the separation is a good measure of the effect of job conditions on costs. In this extreme example, the cost of the 660 on the highway project was over five times the cost of the 660 on the dam project. In the abrasive rock, tire life at the start of the project was as low as 200 hours per tire. The pan had to be modified with thicker steel. The abuse was reflected throughout the scraper. Although this is admittedly a comparison of extreme conditions, it serves to illustrate several points regarding equipment costs. First, we must be objective in

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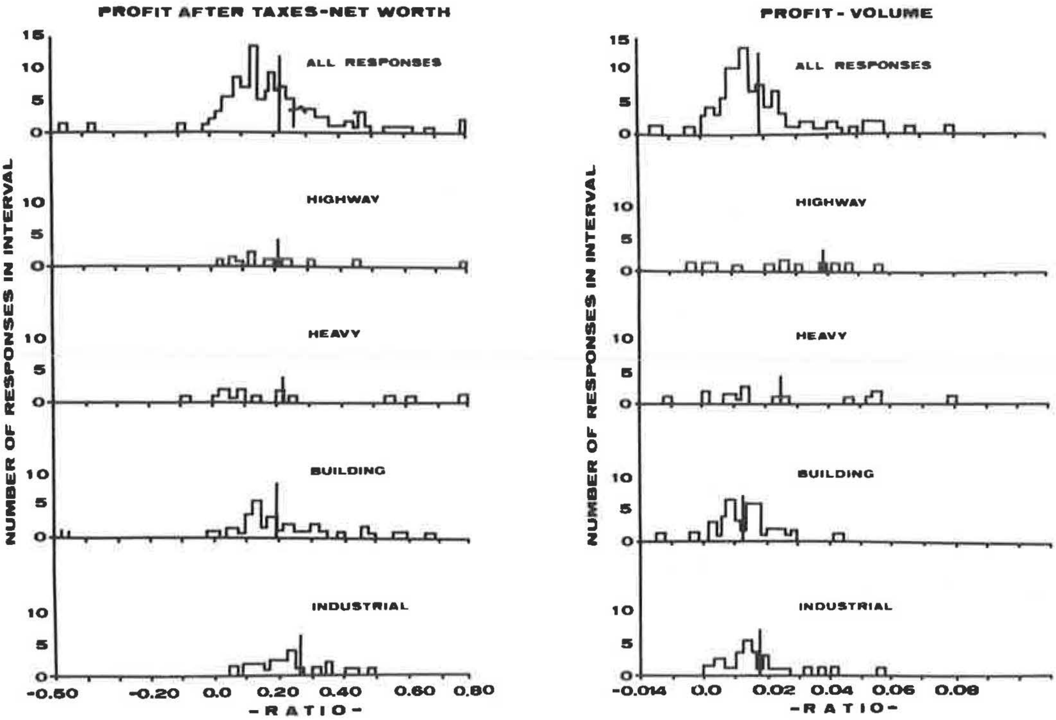

Figure 1. Typical contractor financial ratios.

recognizing the amount of variation in job conditions and the difficulty of obtaining meaningful records. Second, it points up the fallacy of looking only at average costs. It shows the need to compare costs with a standard that represents the best estimate of the average or "standard" conditions under which the equipment will be worked. Most equipment and construction managers today do not have accurate standards for measuring costs nor the deviation from "standard conditions", and the result is a variety of practices that frequently yield a wide variance from predicted costs. Finally, it gives an indication of the potential savings that may be derived from an information system that provides pertinent, timely facts on the condition and costs of equipment. The solution

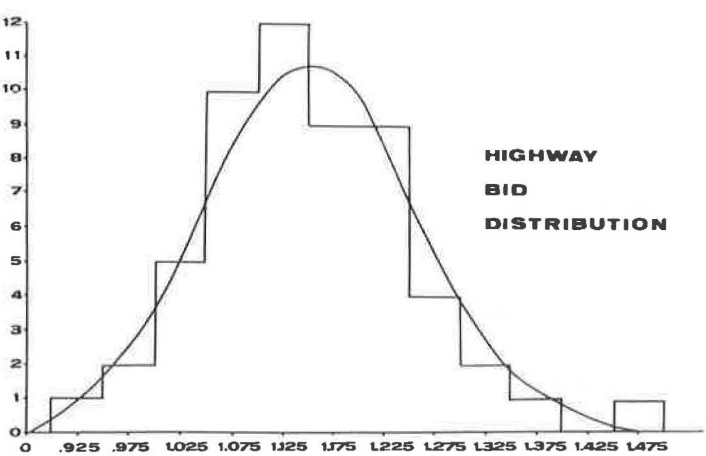

Figure 2. Highway bid distribution—Southwest Texas.

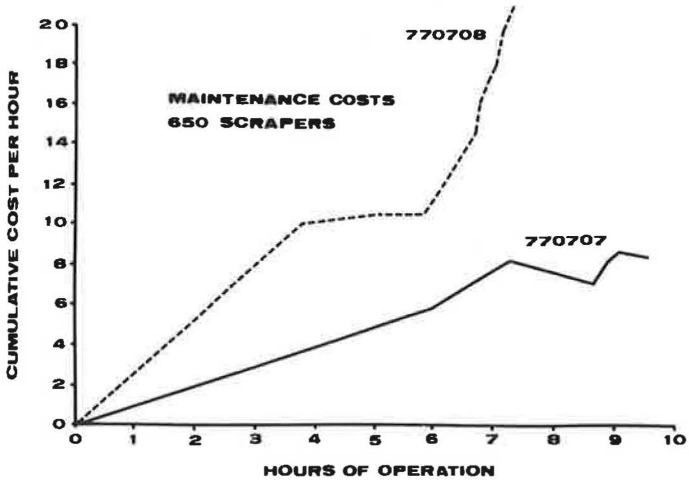

Figure 3. Maintenance variation caused by job conditions.

to the equipment problems of today and tomorrow lies in the equipment manager's access to facts and his ability to use them.

PRESENT EQUIPMENT INFORMATION SYSTEMS

Equipment management is an integral and inseparable part of construction management and may be described by many acceptable definitions. For the purpose of considering information needs for this paper, the functions and information needs of equipment management may be classified as: (a) scheduling, selection and replacement (requiring planning and scheduling information, cost estimates, budgetary control of equipment usage); (b) purchasing and financing (requiring market value analysis, lease-purchase accounting, tax management); and (c) maintenance (requiring budgetary control of maintenance, diagnostic reports, oil sampling, repair history, tire control, PM tickler files, parts inventory). Each of these functions must contribute to attainment of the company's goals for equipment management.

Management generally strives to equip each project with the most suitable equipment, in working condition, where needed, when needed, and with adequate support to provide

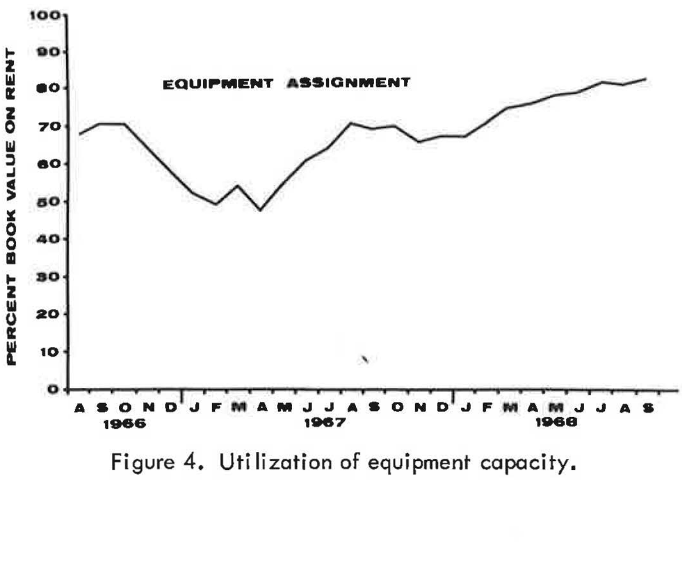

Figure 4. Utilization of equipment capacity.

an acceptable availability level. This must be done at lowest cost consistent with company objectives and generally means operating at a high percentage of total capacity and with maximum equipment performance. Timely, reliable communications are essential for the attainment of these goals.

Scheduling, Selection, and Replacement

The investment policy and related planning activities require involvment of a high percentage of the company's executive time and information capability. Investment in construction equipment for highway contracts must be made with assurance that such investment is desirable on a long-run basis. A strategy for building a construction capability for a given type work requires good communications between those responsible for financial planning, bidding, equipment use, and maintenance, and others responsible for construction management. Success in attaining established goals should be measured by financial ratios or other indicators. Figure 4 is a typical example of such an indicator. It shows the percentage of the total book value of construction equipment that is being used by construction projects. Ratios of the book value of major categories to the total book value is an inexpensive by-product of an integrated system using electronic data processing. Ratios by category sometimes aid in monitoring the planned growth or decline of a specific type of equipment capacity.

One of the most difficult communication areas is that of scheduling equipment. Information must be drawn from knowledge of project schedules and progress, equipment workload, scheduled or required overhauls, and acquisition/displacement plans. Although substantial research has been done at Zachry Company on operations research oriented systems for coordinating the scheduling and allocation of equipment, it still remains a manual system personally accomplished by a vice president. It is one of the areas that will continue to offer great challenge and opportunity for system development.

Equipment may be acquired to develop or expand a specific capability, to replace equipment that has become uneconomical to continue to operate, or to displace equipment that has become obsolete by new equipment developments. Information desirable when acquiring new equipment includes production estimates and data for comparative cost studies. Data on which to base standardization decisions is very desirable. Time-lapse photography, stopwatch time study, work sampling, and other measurement techniques provide information that will become increasingly important as contractors approach the practical use of computer simulation in equipment selection and estimating. Figure 5 shows an estimate based on computer simulation. Information requirements include detail equipment specifications, job quantities and design information, and adequate equipment cost data.

When faced with a replacement or acquisition decision, it is often a good time to review costs of present similar equipment and verify the ownership and repair rates in

H. B. ZACHRY COMPANY
JOB 1472 EL PASO HIGHWAY

EARTHWORK ESTIMATE
MARCH 08, 1968

PAG 2

	HAUL STATIONS	DIST(FT) GRADE(%)	QUANTITY(CY) FIN AREA(SY)		NO.	CLASS	DAILY RATE	HOURLY RATE	HRS/ DAY	MIN /HR	PROD/ UNIT	CY/ HOUR	UNIT COST	TOTAL COST	TOTAL HOURS
CUT	333+94.84 - 336+ 0.0	1869.6	29213.1	HAUL	3	HU64570	25.90	19.94	10.0	50	243	731	0.111		
FILL	315+63.47 - 316+71.95	-4.9	13124	LOAD	2	TA73500	17.74	13.84	10.0	50	365	731	0.051	4736.40	39.[illegible]
CUT	322+36.31 - 324+ 0.0	642.2	6040.9	HAUL	3	HU64570	25.90	19.94	10.0	50	300	901	0.090		
FILL	316+71.95 - 316+98.26	-4.1	7147	LOAD	2	TA73500	17.74	13.84	10.0	50	450	901	0.042	794.47	5.7
CUT	318+ 0.0 - 319+ 0.0	111.4	2144.9	HAUL	2	HU64570	25.90	19.94	10.0	50	339	679	0.080		
FILL	316+98.26 - 318+ 0.0	-4.2	8544	LOAD	2	TA73500	17.74	13.84	10.0	50	339	679	0.055	288.36	3.2
CUT	321+ 0.0 - 322+36.31	245.4	1947.0	HAUL	3	HU64570	25.90	19.94	10.0	50	327	983	0.082		
FILL	319+ 0.0 - 321+ 0.0	-3.5	14650	LOAD	2	TA73500	17.74	13.84	10.0	50	491	983	0.038	234.81	2.[illegible]
CUT	330+ 0.0 - 333+94.84	604.2	46155.9	HAUL	3	HU64570	25.90	19.94	10.0	50	297	893	0.091		
FILL	324+ 0.0 - 330+ 0.0	-7.4	25508	LOAD	2	TA73500	17.74	13.84	10.0	50	446	893	0.042	6126.26	51.7
CUT	371+29.92 - 373+61.08	3292.7	247816.9	HAUL	5	HU64570	25.90	19.94	10.0	50	186	931	0.145		
FILL	336+ 0.0 - 343+ 3.33	-7.0	44341	LOAD	2	TA73500	17.74	13.84	10.0	50	465	931	0.040	45913.31	255.[illegible]
CUT	349+ 0.0 - 353+ 0.0	455.0	58771.9	HAUL	3	HU64570	25.90	19.94	10.0	50	306	919	0.088		
FILL	343+ 3.33 - 349+ 0.0	-9.4	31573	LOAD	2	TA73500	17.74	13.84	10.0	50	459	919	0.041	7583.23	53.[illegible]
CUT	365+ 0.0 - 371+29.92	1138.7	639819.9	HAUL	3	HU64570	25.90	19.94	10.0	50	244	733	0.111		
FILL	353+ 0.0 - 365+ 0.0	-13.0	87848	LOAD	2	TA73500	17.74	13.84	10.0	50	366	733	0.051	103458.00	372.[illegible]

Figure 5. Computer-prepared equipment estimate.

H. B. ZACHRY COMPANY

EQUIP. NO. 330629
DESCR.
COST 0
RESERVE 0
BK. VALUE 0

EXCEPTION REPORT OF UNITS WITH RELATIVELY HIGH REPAIR COSTS INCURRED TO DATE OR DURING THE 30 DAY PERIOD ENDING 07-30-68

ESTIMATED LIFE 0
TO DATE LIFE 0
REMAINING LIFE 0
*** HISTORICAL RECAP BY INQUIRY

COMMENTS	YR	MO	SEV	PRODUCTIVE DAYS	PRODUCTIVE HOURS	MAINTENANCE COSTS LABOR	PARTS	TIRES	REPAIRS	OTHER	TOTAL	REPAIR CREDITS	OWNERSHIP COSTS	CREDITS	VARIANCE REPAIR	OWNER	TOTAL
CURRENT TREND	68	07	100	28-	17-	4	0	0	0	0	4	34-	0	173-	30	173	203
BY MONTHS	68	06	100	18-	17-	4	0	0	0	0	4	34-	0	117-	30	117	147
	68	04	100	0	0	79	721	0	111	0	911	0	0	0	911-	0	911-
	68	03	100	7-	35-	67	0	0	0	0	67	70-	0	75-	3	75	78
	68	02	100	0	0	0	0	19	0	0	19	0	0	0	19-	0	19-
PRIOR YEARS	67		100	205-	1226-	489	650	321	73	0	1533	2452-	0	2419-	919	2419	3338
	66		100	309-	1586-	1058	2870	324	90	0	4342	3172-	5	2165-	1170-	2160	990
	65		100	332-	1514-	125	133	235	36	0	529	3028-	5	2324-	2499	2319	4818
	64		100	366-	1639-	213	589	456	229	0	1487	3278-	424	2562-	1791	2138	3929
	63		100	366-	1838-	221	1148	582	219	0	2170	3676-	2192	2562-	1506	370	1876
	62		100	0	997-	318	592	585	15	20	1530	1994-	3653	2275-	464	1378-	914-
	61		100	286-	1740-	171	238	834	74	163	1480	3480-	6090	2002-	2000	4088-	2088-
	60		100	202-	1730-	60	4	15	24	0	103	3460-	5534	1414-	3357	4120-	763-
TOTALS TO DATE				2119-	12339-	2869	6945	3371	871	183	14179	24678-	17903	18088-	10499	185	10684

Figure 6. Repair cost report generated from exception or by inquiry.

use. Figure 6 shows the cost history of a piece of equipment that is available upon inquiry by individual equipment number. The information is also available in plot form (Fig. 7), which in this case has the costs converted to the present worth of money. Other information available upon inquiry includes a history of the use of a particular piece of equipment. Since the prediction of maintenance costs of new equipment is of major concern, it is very useful when reviewing repair costs for a piece of equipment to know

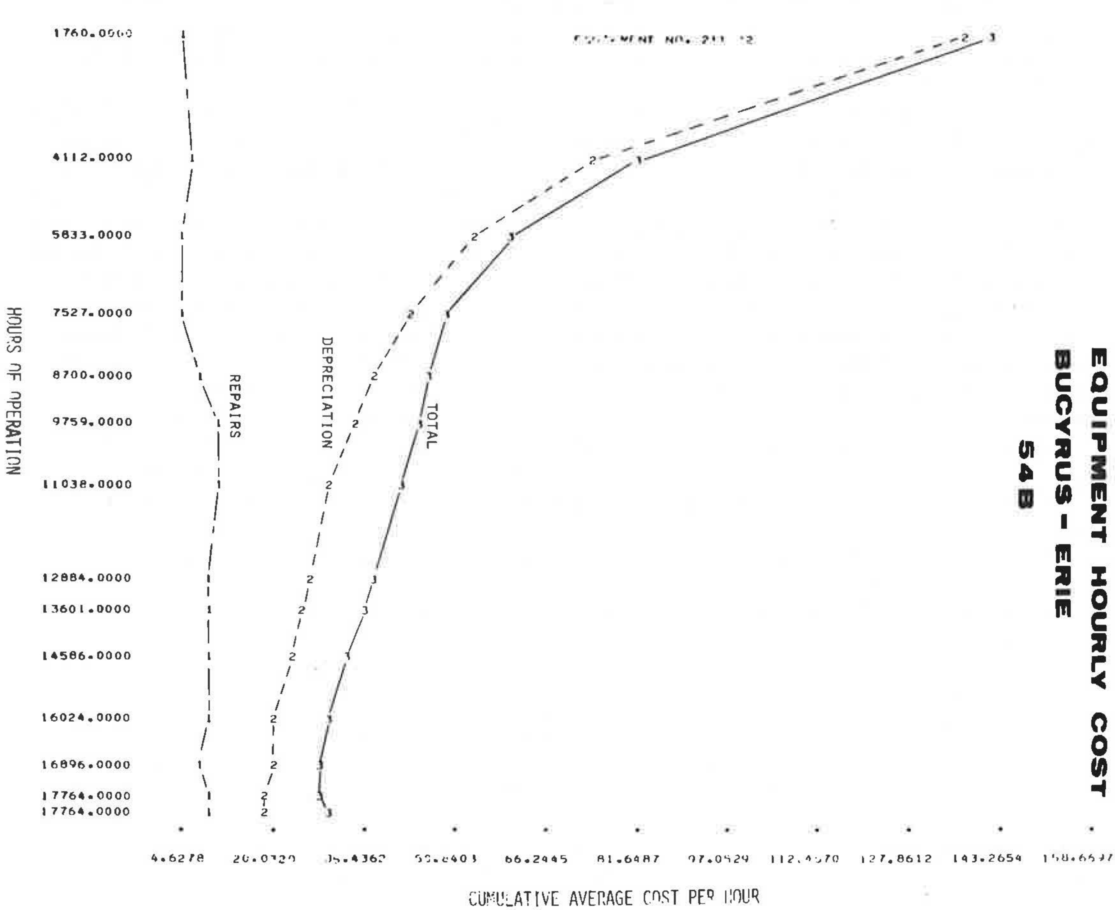

Figure 7. Computer-prepared plot of equipment cost history.

explicitly under what conditions the equipment worked. The lost work of the machine out of production for repairs may be reasonably estimated and retained, but one of the unknown costs at present is the cost of equipment downtime. The task of measuring the cost of an idle spread or crew is more difficult and the information harder to retain and use.

Cost estimates at H. B. Zachry Company are continually monitored and maintained to provide a measure of performance for managers and budgetary control over equipment costs. Various reports are produced to compare trends for all company equipment and to compare actual and estimated costs by major classifications of equipment, such as hauling units and cranes. The comparisons are made to the level of Cat 660 parts costs per hour for measuring maintenance performance and for adjusting estimates for overseas work. In addition to estimating and measuring maintenance performance, the cost estimates are used at H. B. Zachry Company to allocate equipment charges to work in approximately the manner in which the work is estimated. Because the projects are charged in this manner, the estimates become a major factor in planning the job and, therefore, in the scheduling of the equipment.

Most contractors allocate the cost of their equipment to the individual contract performed, but in some companies maintenance and depreciation charges are made directly to the project to which the equipment is assigned. The common practice in the larger companies is to use a standard rate approach, and systems combining a time charge and a use charge have been shown to have substantial advantages over other systems. In a few of the larger companies, several rates may be used under different conditions, and age is often a basis for using a reduced rate. Where a use charge is applied, the system is usually similar to a payroll system with labor distribution. At H. B. Zachry Company, use is reported on a weekly equipment time card and from the time cards submitted, rates are applied and an equipment use register and equipment distribution journal is prepared for each project.

Two uncommon features of the Zachry system include a double allocation of the time charge and the use of adjustments for severe conditions. Figure 8 shows an equipment distribution journal that uses a utilization factor and a severity factor. Equipment costs are allocated to distribution codes within a project by daily and hourly rates. The daily rate is converted to an hourly rate by the use of a utilization factor that may be the same throughout the project or may vary with distribution codes. The cost difference between the estimated utilization and the utilization actually reported is charged to a project overhead account. Therefore, the overhead receives a credit if the equipment is used more than the estimated utilization and a debit if the utilization is below the estimate. This system gets all of the cost allocated to the items where the cost was estimated as well as providing for some operations to be double-shifted while others are single-shifted. The utilization factor and the severity factor are estimated for each item when a project is bid. Each reflects an estimated deviation from the standard conditions on which our rates are based, and the allocation of actual cost to the projects are based on these factors. The result is a system in which estimated costs and allocated costs are quite comparable.

Costs are accumulated by category of equipment for each project cost item and may be printed upon request. At the completion of each project, a final cost report is prepared that shows the number of hours and amount of money allocated to each type of equipment used on each cost item.

Purchasing and Financing

Substantial savings may be realized in these functions through the use of a good information system and well-maintained records. These savings may also be realized through discounts, tax planning and credits, reduced interest rates, and more favorable lease agreements and sales prices. One of the advantages of good machine-readable equipment records is the ability to simulate the effect of proposed leasing plans, revenue agent contentions, and other equipment policies. Priority replacement lists compiled from cost data may provide a guide for purchase decisions and basis for cash requirements forecasting. They cannot be complete due to uncertainty of future contracts,

// JOB TAPESORT

H. B. ZACHRY COMPANY
EQUIPMENT DISTRIBUTION JOURNAL

PAGE

PERIOD ENDING: 10/05/68 — G/L OR JOB 1450 DE CORDOVA DAM

G L OR JOB	DISTRIBUTION CODE	SUB-DISTRIBUTION CODE	EQUIPMENT NUMBER	D H	CHARGEABLE DAYS & HOURS: RENTAL DAYS	CHARGEABLE DAYS & HOURS: PROD HOURS	UTIL FACTOR	SEVER FACTOR	RATES: DAILY	RATES: HOURLY	RATES: HOURLY ALLOCA	RENTAL AMOUNT
400	841	841	900049	H		13	130	1.00	.23	.40	.05	7
						13*						7 *
400	1024	1024	548601	H		21	130	1.00	.93	.82	.21	21
						21*						21 *
400	1029	1029	270518	H		9	130	1.00	1.28	.49	.30	7
400	1029	1029	270522	H		18	130	1.00	1.28	.49	.30	14
400	1029	1029	295401	H		3	130	1.00	14.54	10.65	3.36	43
400	1029	1029	345160	H		4	130	1.00	9.78	6.60	2.26	36
400	1029	1029	453509	H		3	130	1.00	10.47	7.48	2.42	29
400	1029	1029	561410	H		9	130	1.00	2.11	1.47	.49	17
400	1029	1029	600401	H		1	130	1.00	5.73	4.41	1.32	6
400	1029	1029	642105L	H		9	130	1.00	6.79	3.26	1.57	44
400	1029	1029	647001	H		9	130	1.00	24.94	20.00	5.76	232
400	1029	1029	647002	H		5	130	1.00	24.94	20.00	5.76	129
400	1029	1029	734603	H		18	130	1.00	11.30	7.29	2.61	178
400	1029	1029	741032	H		9	130	1.00	12.63	7.07	2.91	91
400	1029	1029	767006L	H		9	130	1.00	8.39	6.56	1.94	76
						106*						902*
400	1140	1143	254731	H		2	130	1.00	1.30	1.90	.30	5
400	1140	1143	453509	H		11	130	1.00	10.47	7.48	2.42	109
400	1140	1143	515505	H		12	130	1.00	3.23	3.01	.75	46
400	1140	1143	549402	H		1	130	1.00	1.63	1.13	.38	1
400	1140	1143	595102	H		5	130	1.00	6.28	5.51	1.45	35
400	1140	1143	642105L	H		2	130	1.00	6.79	3.26	1.57	10
400	1140	1143	647001	H		2	130	1.00	24.94	20.00	5.76	52
400	1140	1143	767006L	H		2	130	1.00	8.39	6.56	1.94	18
400	1140	1143	886503	H		4	130	1.00	12.59	11.45	2.91	58
						41*						334*
400	1150	1153	270518	H		13	130	1.00	1.28	.49	.30	10
400	1150	1153	270522	H		25	130	1.00	1.28	.49	.30	21
400	1150	1153	453509	H		6	130	1.00	10.47	7.48	2.42	60
400	1150	1153	515505	H		4	130	1.00	3.23	3.01	.75	15
400	1150	1153	549402	H		2	130	1.00	1.63	1.13	.38	3
400	1150	1153	561410	H		13	130	1.00	2.11	1.47	.49	25
400	1150	1153	594302	H		8	130	1.00	1.85	.94	.43	10
400	1150	1153	595102	H		19	130	1.00	6.28	5.51	1.45	133
400	1150	1153	600401	H		12	130	1.00	5.73	4.41	1.32	69
400	1150	1153	642105L	H		29	130	1.00	6.79	3.26	1.57	141
400	1150	1153	647001	H		15	130	1.00	24.94	20.00	5.76	386
400	1150	1153	647002	H		12	130	1.00	24.94	20.00	5.76	309
400	1150	1153	734603	H		25	130	1.00	11.30	7.29	2.61	247
400	1150	1153	741032	H		13	130	1.00	12.63	7.07	2.91	131
400	1150	1153	767006L	H		29	130	1.00	8.39	6.56	1.94	247
400	1150	1153	886503	H		11	130	1.00	12.59	11.45	2.91	159
						236*						1966*
400	1160	1161	270518	H		8	130	1.00	1.28	.49	.30	6
400	1160	1161	561410	H		8	130	1.00	2.11	1.47	.49	15
400	1160	1161	741032	H		8	130	1.00	12.63	7.07	2.91	80
						24*						101*
400	1270	1271	214552	H		1	130	1.00	13.33	8.82	3.08	13
400	1270	1271	901408	H		2	130	1.00	.75	.68	.17	1

Figure 8. Distribution journal for equipment cost allocation.

but a high percentage of equipment will be common to whatever contracts are forthcoming.

Maintenance

Anyone can do a complete maintenance job—at a premium price—but facts and good communication are essential for getting the maximum use between overhauls and maintaining the proper balance between maintenance costs and downtime costs.

For overall control of maintenance, the estimates used for bidding are also used for budgeting control of maintenance expenditures. The level at which budgetary control is attempted varies significantly between companies. H. B. Zachry Company uses three levels of budgetary control as follows: (a) functional type of equipment, e.g., hauling units; (b) type of equipment by model and size, e.g., Cat 660 scrapers; and (c) type of expenditure, e.g., parts. A report showing these levels is shown in Figure 9. The budgetary control is usually applied on a cost per unit basis with Zachry Company using days and hours for units of use. Miles, weeks, months, and production quantities are appropriate units for measurement of use that have been employed in the past but are

H. B. ZACHRY CO.
ACTIVE EQUIPMENT- SUMMARIZED BY CLASS
THRU 12-31-67

CLASS YR NO.	DAYS OWNED	PRODUCTIVE DAYS	HOURS	MAINTENANCE COSTS LABOR	PARTS	TIRES	REPAIR	SUNDRY	TOT REP COSTS	TOT REP CREDITS	OWNER COSTS	OWNER CREDITS	INCEPTION TO DATE COSTS	CREDITS	VAR
GR33060 GRADERS-SP DIES TANDEM DR 115 HP															
CURRENT RENTAL RATE-HR									2.00		2.08		4.08		
GR33090 GRADERS-SP DIES TANDEM DR 150 HP															
60-906	2700	2010-	8160-	4867	11402	6530	17309	2	40130	19939-	20105	16698-	60235	36637-	23598-
63-908	1630	1545-	10414-	2996	8695	3540	1409	24	16664	26376-	23099	13351-	39763	39727-	36-
63-909	1670	1304-	8462-	3820	8062	3718	1093	313-	16380	22198-	22549	11557-	38929	33755-	5174-
63-910	1677	2009-	14854-	2304	6069	1965	130	42	10510	21930-	23391	11261-	33901	33191-	710-
63-911	1660	1439-	8034-	3267	4096	3057	279	56	10755	20279-	23178	12567-	33933	32846-	1017-
63-912	1624	1475-	7559-	2648	4693	1524	5	31	8901	18667-	23094	11974-	31995	30641-	1354-
64-913	1438	1129-	5038-	2361	2954	3662	314		9291	13097-	22798	10080-	32089	23177-	8912-
64-914	1260	1071-	6728-	2062	5392	3854	1821	226-	12903	18356-	21425	10661-	34328	29057-	5271-
65-915	313	711-	4549-	991	4418	1533	5	61	7008	11993-	18535	6770-	25543	18763-	6780-
66-916	718	547-	3812-	142	56	1443			1641	10625-	16363	6694-	18004	17319-	685-
66-917	458	432-	2665-	655	519	786			1960	7784-	12175	7359-	14135	15143-	1008
66-918	420	403-	2589-	304	280	903			1487	7806-	11577	6081-	13064	13887-	823
67-919	360	357-	2235-	241	170	463	112		986	6920-	10210	5665-	11196	12585-	1389
TOTAL	16544	14452-	85059-	26658	56806	32998	22477	323-	138616	206010-	248499	130718-	387115	336728-	50337-
UNIT-COST-HR				.31	.67	.34	.26		1.63	2.42	2.92	1.54	4.55	3.96	.59
CURRENT RENTAL RATE-HR									2.60		2.48		5.08		
GR33100 GRADERS-SP DIES TANDEM DR 225 HP PS															
65-001	990	902-	5601-	1633	3987	8124	4979	111	18838	19348-	35809	24753-	54647	44101-	10546-
66-002	510	441-	2662-	509	663	4066			5238	10408-	25905	13138-	31143	23546-	7597-
67-003	199	110-	695-	202	344	3451		34	4033	2780-	11657	3601-	15690	6381-	9309-
67-004	120	68-	549-	215	182				397	2196-	6120	2563-	6517	4759-	1758-
TOTAL	1819	1527-	9507-	2559	5176	15647	4979	145	28506	34732-	79491	44055-	107997	78787-	29210-
UNIT-COST-HR				.27	.54	1.65	.52	.02	3.00	3.65	8.36	4.63	11.36	8.29	1.07
CURRENT RENTAL RATE-HR									4.00		5.62		9.62		
GR33185 GRADER-TOWED LIGHT (OFT. TERRACER)															
46-851		540-	81-	16					16	243-		186-	16	429-	413
64-852	1230	547-	90-	79	146			2	227	107-	1017	123-	1244	230-	1014-
TOTAL	1230	1087-	171-	95	146			2	243	350-	1017	309-	1260	653-	601-

Figure 9. Summary of equipment costs by category.

not at present. Some companies do not summarize their costs by functional type of equipment but carry their budgetary control to a lower level. These systems carry the type of expenditure down to the specific equipment system repaired, i.e., hydraulic system. The desired level depends on the variability of the equipment's use. The more uniform the job conditions are, the greater detail can be effectively maintained.

In order to hold down costs, it is essential that the elements of cost be identified, but how many men are good at filing information? It is difficult for men with an interest in making machinery tick to stay dedicated to maintaining a repair history file. Therefore, in addition to the mechanics keeping a maintenance jacket with each piece of equipment, maintenance costs are processed through a manual system in the home office before entering the automated data processing system. The manual system, as shown in Figure 12, is designed to file invoices for easy reference by vendor and by equipment number. This centralized equipment folder then provides a history of all charges made to that equipment number and includes a copy of the work order that accompanies an invoice. The file therefore contains itemized lists of parts installed on the machine. It becomes a valuable source of information when considering major overhaul and replacement decisions at the home office. It is also a means of verifying or completing the field-kept maintenance jackets.

The information system should be oriented toward the planned application of mechanics to maintenance rather than the collection of average cost figures. Some of the most important maintenance information is that relative to the condition of equipment. Figure 10 shows a report of prior oil samples for a piece of equipment whose most current sample indicated a possible maintenance problem. Our maintenance organization is learning to effectively utilize this system to prevent costly repairs.

Another system requiring close attention is the control of tire costs. H. B. Zachry's present system is an inventory control card system that is maintained on the job sites.

Laboratory Report

RECEIVED FROM:
H. B. ZACHRY COMPANY
P. O. BOX 21130
SAN ANTONIO, TEXAS 78221

PAGE NO. 10
WRIGHT OIL CO. LABORATORIES
301 S. MEDINA ST.
SAN ANTONIO, TEXAS 78207

THE LAST OIL SAMPLE RECEIVED IS
QUESTIONABLE, NOTE TREND AND
COMMENTS BELOW.

DATE PROCESSED: 9-30-68 JOB NO: 1472 JOB LOCATION:

UNIT NUMBER	SYS CODE	EQUIPMENT DESCRIPTION	SAMPLE DATE	TOTAL ENG. HRS/MILES	ANTI FRZ	MOIS-TURE	FUEL DIL	VISC @ 210° F	FLASH POINT	SAE GRD		SPECTROGRAPHIC ANALYSIS							
										FIELD	LAB	BORON	LEAD	IRON	ALUM	COPPER	CHROME	TIN	SILIC
643005	A1B	EUC TS14 SCRAP 14YD 67	06-30	1,084	N				460	040	040	16	7	27	16	000	031	009	6
		FRONT ENG - DIESEL	07-14	1,190	N				450	040	040	3	8	16	15	000	025	006	5
			07-28	1,306	N				450	040	040	8	6	36	19	000	036	008	6
			08-11	1,404	N				460	040	040	11	13	26	14	000	019	009	8
			08-25	1,488	N				445	040	040	2	12	10	17	000	029	009	15
			09-08	1,592	N				455	040	040	17	13	32	16	000	031	007	45

ATTENTION ** NOTICE THAT THE LAST RATING OF SILIC EXCEEDS THE ESTABLISHED SAFETY LIMIT.

Figure 10. Laboratory report from oil sample analysis.

A number of companies have put this system on their computer and it will be one of the next systems to be automated at Zachry Company. The Caterpillar Tractor Company has prepared a brochure describing a system of controlling tire costs that will be the general basis for the conversion to a centralized system. A tire exchange card (Fig. 11) that can be marked in the field and read by a terminal will be used to keep track of their use.

Although significant refinements have been made in controlled maintenance systems, the basic ingredients are still a well-defined list of items to check at each maintenance level and a tickler file to insure that the planned maintenance is carried out. Zachry Company believes there are many advantages to maintaining this tickler file at the job site rather than a central office. With the tickler file and a well-maintained maintenance jacket on each major piece of equipment, a project master mechanic has the information required in almost all circumstances to make good maintenance decisions. The major difficulty experienced in maintaining good job-site equipment information systems is the problem of transferring records between job sites as the equipment is transferred. Documents that should be transferred with each machine include its maintenance jacket, preventive maintenance records, maintenance instructions, lubrication charts, parts catalogue, and any operating instructions.

With the use of consigned parts stocks today and the excellent service provided by equipment dealers, the author subscribes to field control of parts inventory until the cost of parts increases further and the cost of communications systems decreases. Small tools and certain parts, however, that should be transferred between jobs do require a centralized inventory. A perpetual inventory of the larger equipment is, of course, maintained by scheduling and maintenance systems.

THE USE OF ELECTRONIC DATA PROCESSING EQUIPMENT

Equipment systems today combine the experience of several individuals into a total system. The accountant thinks of an equipment information system in terms of depreciation schedules and general ledger entries. The maintenance man visualizes an information system as a work order system he is using or has used in the past. The estimator questions the cost of the certain type of equipment for the job he is bidding and the conditions on which past cost estimates were derived. Top management seeks information on which to make investment decisions and formulate operating policies. The systems analyst in data processing is looking for common interest in order to combine the systems with minimum effort. Considerable progress has been made in the past decade toward reconciling the conflicting information needs of the different functions within contractors' organizations. The interest in utilizing computers has stimulated more communication between groups using the hardware.

Figure 11 shows the retrieval of requested equipment information and the processing of oil sampling data on a daily basis. H. B. Zachry Company is not at present using its EDP equipment for tire activity, inventory, and preventive maintenance reporting, but preliminary studies have been conducted on the application of terminals that read cards with a combination of punched and marked information for reporting tire activity and inventory information. Figure 12 is a proposed mark-sense card for recording tire changes. The company will continue to investigate maintenance systems with an open mind to further standardization and automation. Systems such as the miniaturized analogue computer that mounts on heavy equipment and the variety of new EDP terminals available offer new opportunities to communicate reliable maintenance information between job sites and a centralized data processing installation quickly enough to assist field maintenance personnel.

Figure 13 shows the routine weekly processing cycle, which consists primarily of the allocation of equipment costs for budgetary control of the projects. In addition to other changes to the equipment files, documents showing changes affecting the location or status of equipment are processed also and equipment movement and use reports are produced. The keypunched equipment repair bills become transactions in the files that

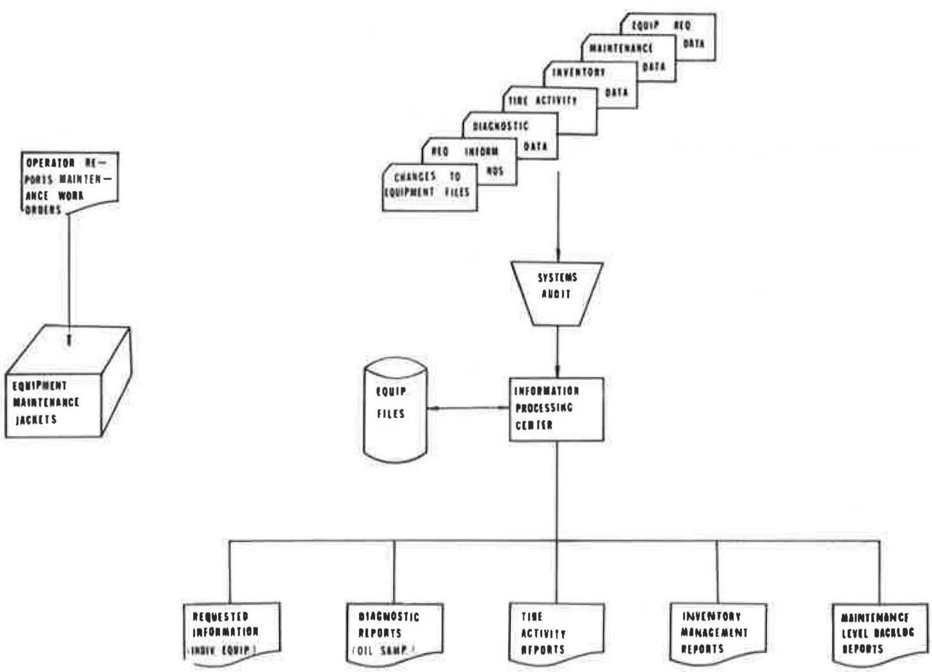

Figure 11. Daily information processing flow for equipment.

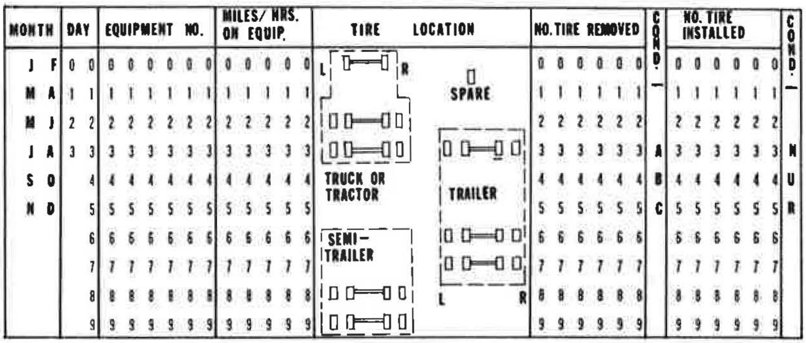

Figure 12. Tire exchange card.

will be entered into the accounting ledger system and into the cost reports. All information entered into the system is carefully edited and reconciled with all other information in the system, and any apparently conflicting information is shown in exception reports. Weekly project cost reports show estimated vs actual equipment costs.

An equipment cost ledger is processed monthly showing all equipment transactions for the month, and several analysis reports are prepared to show a summary of equipment operations and also to show unusual cost variances.

Information is retained in machine-readable form on a combination of magnetic tapes and disk files. Table 1 lists the contents and use of the files retained at H. B. Zachry Company. The files are continually being extended and new information added for further analysis or control. At this time, it is not economically feasible to consider complete retention of specification and maintenance files on magnetic storage media. One small file of equipment specification data for simulation of earth-moving operations is maintained. An additional file, not shown in Table 1, contains trends of costs, utilization, and various ratios that are used as a follow-up on management policies. The file

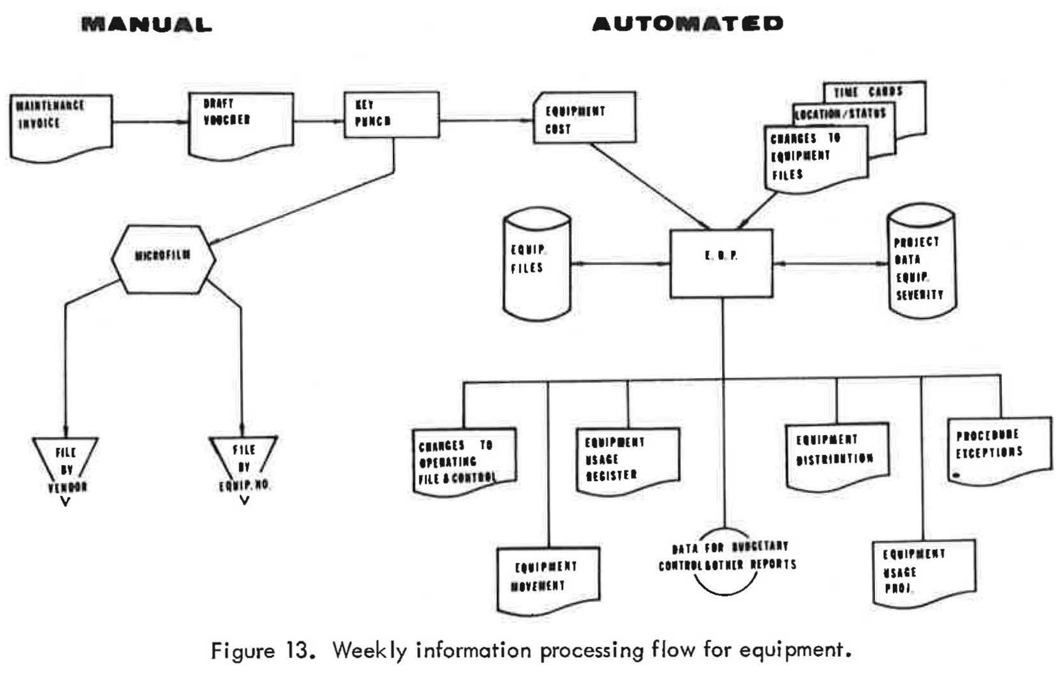

Figure 13. Weekly information processing flow for equipment.

TABLE 1

EQUIPMENT INFORMATION STORAGE

FILE	CONTAINS	USE
EQUIPMENT CATEGORY	UTILIZATION ESTIMATES COST ESTIMATES SHIPPING DATA	ESTIMATING NEW WORK ALLOCATING COST TO PROJECTS (WORK BREAKDOWN) CONTROLLING MAINTENANCE EXPENDITURES SELECTION OF CATEGORIES FOR MAINTENANCE AND SCHEDULING SYSTEM
EQUIPMENT BY INDIVIDUAL PIECE	DEPRECIATION DATA LOCATION AVAILABILITY STATUS MECHANICAL CONDITION USAGE LAST MAINTENANCE CHECK DATE FINANCING OR LEASING INFO.	DEPRECIATION SCHEDULES ALLOCATION OF COST TO PROJECTS CONTROL OF UTILIZATION CONTROL OF DIAGNOSTIC CHECKS PROJECT EQUIPMENT INVESTMENT
COST HISTORY (ACTIVE EQUIPMENT)	COST HISTORY UTILIZATION HISTORY	MAINTENANCE COST CONTROL ESTABLISHMENT OF COST ESTIMATES COMPARISON OF EQUIPMENT TYPES
USAGE TRANSACTIONS	USAGE HISTORY	CONTROL OF EQUIPMENT POLICIES ANALYSIS OF SEVERITY COST
DIAGNOSTIC FILE	OIL CONTAMINANT AMOUNTS	INDICATES EQUIPMENT MALFUNCTION OR EXCESSIVE WEAR
COST HISTORY (INACTIVE EQUIPMENT)	COST HISTORY UTILIZATION HISTORY	SPECIAL STUDIES SUCH AS RESALE VALUE ANALYSIS

of inactive equipment is currently being substantially reduced from the size shown by limiting it to major categories of equipment. An ABC inventory analysis shows that less than a fourth of our equipment accounts for over three-fourths of our cost.

The approximate purchase price of the storage media is $1.80 and $50.00 for the tape and 2311 disk respectively. Actual cost varies significantly depending on recording density, whether packed or unpacked, number of tracks, record blocking, and other considerations. Table 2 gives the approximate computer cost at H. B. Zachry Company of maintaining and using equipment records stored on 2311 disk packs. These figures are based on the use of an IBM 360 model 30 computer with tape and disk storage. The IBM rental price of the actual equipment used for these files at H.B. Zachry Company is slightly in excess of $13,000 per month with less than 12 percent of its use pertaining to equipment. Present costs for routine processing of equipment information amount to about 0.2 percent of equipment expenditures, and costs of systems improvements and special reports amount to another 0.1 percent.

Reliability is the major problem in the construction industry due to the turnover of field personnel and variety of job conditions encountered. One of the problems in achieving reliable information has been the difficulty in assigning responsibility for information other than dollar expenditures. There is also the question of whether the expense of the duplication in a double-entry accounting system is justified for information other than dollar expenditures. The author feels that the unit of measure of equipment use, whether it be hours or miles or other measure, is essential enough to warrant double-entry control. In addition to the reported hourly use, 365 days per year should be accounted for. The use of self-checking numbers should be considered. Such techniques, however, do not take the place of establishing system responsibility. The development of remote terminal capability is rapidly improving this problem by providing the user at the field office with access to information required to maintain and control his own system.

EQUIPMENT INFORMATION SYSTEMS GOALS

The information system provides the communications necessary to attain the management goals of achieving the optimum levels of most suitable equipment; in the best condition economically feasible; where needed, when needed; with adequate support to provide acceptable service; and at lowest cost consistent with company objectives.

TABLE 2

EXAMPLE OF DATA PROCESSING REQUIREMENTS
FOR EQUIPMENT INFORMATION STORAGE AND RETRIEVAL

FILE	PIECES OF EQUIPMENT (OR CLASSES)	CHAR/PIECE OF EQUIP	DISK CYLINDERS REQUIRED	ANNUAL COST TO MAINTAIN	TIME TO SEARCH FOR INDIV PIECE	TIME TO DISPLAY DATA FOR INDIV PIECE	TIME TO SCAN FILE	COST TO SCAN FILE
EQUIPMENT CATEGORY	717	300	10	575	.2 SEC	1 SEC	30 SEC	.42
EQUIPMENT BY INDIVIDUAL PIECE	3300	400	45	1125	.3 SEC	1 SEC	2.6 MIN	2.16
DIAGNOSTIC FILE (OIL SAMPLING)	500	750	15	900	.2 SEC	1 SEC	45 SEC	.65
COST HISTORY (ACTIVE EQUIPMENT)	2750	3100	240	2700	.4 SEC	5 SEC	16 MIN	13.32
USAGE TRANSACTIONS	2750	5100	550	5850	1 SEC	5 SEC	30 MIN	25.00
COST HISTORY (INACTIVE EQUIPMENT)	8500	3100	750	8737	1.5 SEC	5 SEC	50 MIN	41.70

Management from the top is essential for attaining these goals and requires proper purchasing decisions, strong maintenance policies, and establishment of clear standards for performance. This requires effective communication systems and the systematic analysis of meaningful records.

To be meaningful, records must be more than just expenditures and more than just averages. They must be pertinent to the day-to-day decisions. They must be reliable enough to instill confidence in them. They must be where they are needed at the time they are needed. They must be acquired at reasonable cost and convenience. The information system must be simple and flexible enough to survive in the construction project environment. All of these features are necessary, but of primary importance is that the information system must be wanted and used by those who need the facts.

The author believes the need for equipment information and the trend of systems will be as follows:

1. More emphasis placed on estimating equipment maintenance requirements to aid in utilizing maintenance resources, particularly specialized knowledge and skills. This should become more feasible due to (a) less expensive and more reliable systems of recording, retaining, and relating data pertaining to equipment cost—i.e., fuel consumption, mileage, yards produced, tire replacement reasons, etc; (b) greater use of diagnostic equipment and control of maintenance; and (c) more convenient application of mathematical techniques of curve-fitting, multi-variable regression analysis, life cycle theory, and use of computers for estimating maintenance costs.
2. A closer examination of alternatives prior to making major purchases or repair decisions. Eventual use of mathematical models for aid in selection and use of mathematical programming techniques may be used to evaluate for each major breakdown the cost of repairing in the field shop, moving the equipment to the home office shop or other field shop, or sending it back to the dealer.
3. More use of data processing equipment for follow-up of equipment programs. Reminders of work not performed can thereby be impersonal and management can give recognition of accomplishments more effectively.

4. Allocation of equipment cost to the work performed should show significant improvement in accuracy in the next few years with increased benefits in project supervision.

In summary, heavy and highway contracting is not a stable business, and the multitude of reasons for wide variations in cost and performance will make information needs and abilities a dynamic process. The long payout period of equipment expenditures in relation to highway contract size and duration will continue to make control of equipment costs a major challenge. Reliable communications are essential to managing equipment whether or not highly automated by computer. As H. L. Gantt wrote in 1916, "Action based on opinion will lose in competition with action based on facts."

Average Production Rates for Major Equipment*

•A CONCISE summary of average production rates for key road construction equipment units is presented here for reference use. These rates were developed by analyzing data from field research studies conducted by the U. S. Bureau of Public Roads. The equipment studied was operated under a variety of job conditions and management practices during construction of several hundred highway projects located throughout the United States.

Individual job cases with production rates of ± 35 to 50 percent of the average were not uncommon. In extreme cases, production rates varied from the average by as

TABLE 1

OBSERVED AVERAGE PRODUCTION RATES FOR MAJOR EQUIPMENT: EXCAVATION OPERATIONS
(Rates for Individual Jobs Can Be Expected To Range Between 50 and 150 Percent of Average Rates)

Class of Equipment	Total No. of Observed Machines	Average Production per Hour of:		
		Productive Time	Net Average Working Time	Scheduled Shift Time
A. Power shovels—Roadway excavation (1½-5 cubic yards)	80	104 "units"	67 "units"	57 "units"
Multiply "units" by dipper struck capacity (cubic yards) to obtain pay yards per hour				
B. Power shovels—Borrow pit excavation (1½-2 cubic yards)	4	178 "units"	128 "units"	120 "units"
Multiply "units" by dipper struck capacity (cubic yards) to obtain pay yards per hour				
C. Draglines—Roadway and pit excavation (1-5 cubic yards)	9	147 "units"	94 "units"	83 "units"
Multiply "units" by bucket struck capacity (cubic yards) to obtain pay yards per hour				
D. Elevating graders pulled by crawler tractors	8	707 pay yards	541 pay yards	484 pay yards
E. Scrapers pulled by crawler tractors (8-26 cubic yards)	78			
1. 250 ft apparent haul distance[1]		12.4 loads	10.4 loads	8.2 loads
2. 500 ft apparent haul distance		9.4 loads	8.2 loads	6.8 loads
3. 750 ft apparent haul distance		7.9 loads	7.0 loads	5.9 loads
4. 1000 ft apparent haul distance		7.0 loads	6.3 loads	5.4 loads
5. 1250 ft apparent haul distance		6.5 loads	5.9 loads	5.1 loads
For scrapers up to 21 cubic yards struck capacity, multiply loads by 80 percent of struck capacity (cubic yards) to obtain pay yards per hour				
For scrapers over 21 cubic yards struck capacity, multiply loads by 70 percent of struck capacity (cubic yards) to obtain pay yards per hour				
F. Scrapers pulled by rubber-tired tractors (5-32 cubic yards)	246			
1. 250 ft apparent haul distance[1]		30.3 loads	17.5 loads	11.9 loads
2. 500 ft apparent haul distance		21.2 loads	14.1 loads	10.2 loads
3. 750 ft apparent haul distance		16.8 loads	11.9 loads	9.1 loads
4. 1000 ft apparent haul distance		14.2 loads	10.6 loads	8.3 loads
5. 1250 ft apparent haul distance		12.5 loads	9.6 loads	7.7 loads
6. 1500 ft apparent haul distance		11.2 loads	8.9 loads	7.2 loads
7. 2000 ft apparent haul distance		9.6 loads	7.8 loads	6.4 loads
8. 2500 ft apparent haul distance		8.5 loads	7.0 loads	5.9 loads
9. 3000 ft apparent haul distance		7.7 loads	6.5 loads	5.5 loads
10. 3500 ft apparent haul distance		7.2 loads	6.1 loads	5.2 loads
11. 4000 ft apparent haul distance		6.8 loads	5.8 loads	5.0 loads
12. 4500 ft apparent haul distance		6.5 loads	5.6 loads	4.9 loads
13. 5000 ft apparent haul distance		6.2 loads	5.4 loads	4.8 loads
For scrapers up to 21 cubic yards struck capacity, multiply loads by 90 percent of struck capacity (cubic yards) to obtain pay yards per hour				
For scrapers over 21 cubic yards struck capacity, multiply loads by 80 percent of struck capacity (cubic yards) to obtain pay yards per hour				

[1]Length of path actually traveled between end of load at cut and start of dump at fill.

*The average production rates published here summarize the results of production rate studies assembled since HRB Special Report No. 68, "Construction and Maintenance", was published in 1962. Many valuable contributions in the preparation of this report were made by Morgan J. Kilpatrick and W. N. Records of the U.S. Bureau of Public Roads, and the Committee on Highway Equipment is indebted to them for making the material available for publication.

TABLE 2

OBSERVED AVERAGE PRODUCTION RATES FOR MAJOR EQUIPMENT: BASE AND PAVEMENT OPERATIONS
(Rates for Individual Jobs Can Be Expected To Range Between 65 and 135 Percent of Average Rates)

Class of Equipment	Total No. of Observed Machines or Plants	Average Production per Hour of:		
		Productive Time	Net Available Working Time	Scheduled Shift Time
A. Portable-type crushing plants	11	255 tons	192 tons	140 tons
B. Roadmix stabilization machines				
1. Towed by tractors	5	645 square yards	570 square yards	422 square yards
2. Self-propelled	12	1303 square yards	1118 square yards	699 square yards
C. Continuous-type stabilization plants	4	441 tons	364 tons	326 tons
D. Continuous-type bituminous hot-mix plants				
1. 90-175 tons per hour rated capacity	13	148 tons	114 tons	90 tons
2. 250-500 tons per hour rated capacity	3	342 tons	294 tons	255 tons
E. Batch-type bituminous hot-mix plants (1-5 tons)	61	74 batches	53 batches	41 batches
Multiply batches by batch size (tons) to obtain tons per hour				
F. Concrete pavers (34E mixers)				
1. Double drum type	91	97 batches	63 batches	51 batches
2. Triple drum type	9	120 batches	75 batches	59 batches
Multiply batches by batch size (cubic yards) to obtain cubic yards per hour				
G. Concrete plants (108-254S)				
1. One cascading drum- or turbine-type mixer	15	34 batches	25 batches	20 batches
2. Two cascading drum-type mixers	9	67 batches	40 batches	37 batches
Multiply batches by batch size (cubic yards) to obtain cubic yards per hour				

much as minus 75 percent or plus 125 percent. In general, paving work had the least and excavation work the most variation.

Each type of key equipment studied experienced lost time due to a variety of delay causes. The magnitude of these time losses is reflected in the production rates reported under three different time classifications as follows:

1. Productive time rates, computed with the time for all delays excluded;
2. Net available working time rates, computed by excluding only the time for individual delays that lasted 15 minutes or more; and
3. Scheduled shift time rates, computed by excluding only the time for individual weather-caused delays that lasted 15 minutes or more.