HIGHWAY RESEARCH RECORD

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Manpower, Maintenance, and Studded Tires

5 Reports

Subject Areas

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Foreword

Changes in employee attitudes and background over a period of time may not be noticed. When the changes are noticed they may be ascribed to the wrong cause. Speakers on the program of the HRB 49th Annual Meeting addressed themselves to this topic.

At a conference session, Joseph N. Froomkin described the ever-heightening level of education attained by employees entering the work force. These employees carry with them to the new job an image of the sort of work they should be assigned. Employers may expect to have dissatisfied employees if job assignments do not meet the expectations. This dissatisfaction can exist for a PhD asked by a large chemical company to perform routine chemical analyses or for graduate engineers assigned to tasks that can be performed equally as well by technicians. The same dissatisfaction develops among high school graduates who perform maintenance work and are asked to clean rest areas or pick up litter. These tasks seem degrading. Labor turnover and unionization can result from this dissatisfaction.

Mechanization of maintenance work seems to offer hope that employee aspirations can be met. LaRue Delp describes the very great strides made toward complete mechanization of maintenance work in Kansas. Further his paper shows that personnel management is only one facet of a well-managed, strongly supported program. But equipment acquisition, repair, and operation may represent as much as 25 percent of highway maintenance expenditures and is worthy of the study evidenced in Delp's paper.

Karrer's paper may not seem to be related to Delp's presentation, yet similar findings are reported. Bergstralh points this out clearly in his discussion. "Before steps are taken to increase the number of engineers employed... it should be worth the effort to find out if the engineering work to be done is equal to or in excess of the numbers of engineers employed." Karrer's is the second large study of engineering manpower that found dissatisfied engineers because work assignments were not challenging enough and did not offer opportunities for the use of engineering judgment. Again quoting Bergstralh, "If managers who are hard pressed to get the work done cannot provide challenging work assignments to the currently employed engineers, there is reason to doubt the need for additional engineers."

A study of equipment procurement is reported in Doom's paper. Generally he found that total guaranteed cost is a promising approach to the subject, but further work must be done by industry in providing bonds for a longer period of time, and other problems of a related nature must be overcome before the process can realize its full potential. It is noteworthy that tire purchase on a guaranteed bid basis has now entered its second cycle in Virginia and is considered to be successful. The experiment on equipment procurement was a natural outgrowth of the initial effort directed toward tire procurement. Similar results should be obtainable if current problems can be overcome.

Studies reported in HRB Records published in 1966 (136 and 171) forecast a pavement wear problem as studded tire usage became widespread. That these forecasts were accurate has now been confirmed in studies by Keyser and by Schonfeld and Smith. Public agencies now must consider the problem of providing for higher initial investments or additional maintenance expenditures to offset the increased wear attributed to widespread use of studded tires in snow-belt states.

To date, despite public acceptance of studded tires, studies have not shown that these extra expenditures are offset by equivalent safety benefits. Wear attributed to studded tires eliminates safety grooves cut to improve vehicle direction stability on wet pavements and shortens pavement striping life during the winter period when repainting is not feasible. Investigations of accident records to determine the effect of studded tire usage on accident rates has not yet shown a reduction in accidents corresponding to usage of studded tires. This could conceivably be related to a common failure to install studded tires on all 4 wheels, which may increase cornering capacity by 50 to 60 percent.

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A Study of the Factors Influencing Attraction and Retention of Engineering Talent With the Ohio Department of Highways

EMMETT H. KARRER, Transportation Research Center, Ohio State University

This report on factors affecting attraction and retention of engineering talent in Ohio and throughout the nation concludes that loss of engineering talent is a serious problem that will probably become more severe. More than 55 percent of the engineers left the Ohio Department of Highways within 3 years, and it is worth noting that low salaries ranked only third among the 5 major causes. Specific suggestions are offered on recruiting, training, and ensuring retention of engineers.

•ALTHOUGH THIS STUDY was initiated by the Ohio Department of Highways, it quickly became apparent that the problem of attracting and retaining engineers in the employment of the state highway department was not unique to Ohio but was a serious problem in many states. Consequently the base of the study was broadened to include information from all state highway departments.

For many years the Ohio Department of Highways has been concerned about the quality and effectiveness of its engineering organization. An engineer-in-training program was initiated in Ohio in 1949, and this program was continued for a period of 10 years. In 1966 an EIT program was re-established in Ohio. As the present version of the training program had not been in force for any appreciable period of time prior to the start of this study in 1967, it was considered by the researchers to be unfair to attempt to critically evaluate that program as part of our study. On the basis of the nearly 100 engineers in training involved in Ohio's EIT program in June 1970 as well as the 70 men who have completed the program and are on permanent assignments within the department, it is proving to be successful.

Reference is also made in this report to the need for construction manuals. Although some manuals have been available for many years within the Ohio Department of Highways, beginning in 1967 they were increased in scope and rewritten in layman's terms, thereby increasing their effectiveness.

MAGNITUDE OF THE PROBLEM

The problem of shortage of engineers and engineering technicians in state highway departments is not new. Shortly after World War II, with the surge of roadbuilding needed to catch up with repair and reconstruction of roads that had been neglected during the war years, the shortage of engineering personnel was very much in the news.

With the initiation of the Interstate Highway Program in 1956, the amount of highway construction throughout the nation increased tenfold, creating a new wave of shortages of engineers. In the past decade this shortage has not been resolved and, if anything, has grown worse. State highway departments not only have failed to attract as many new college graduate engineers as they would like, but they have been losing many competent and experienced engineers.

Paper sponsored by Committee on Maintenance Personnel and Committee on Highway Organization and Administration and presented at the 49th Annual Meeting.

The seriousness of the situation is reflected in the following summary of the figures furnished by all of the states and the U. S. Bureau of Public Roads as part of our study.

Item	All States	Ohio
Total full-time engineers employed during fiscal year 1968	27,273	680
Number of engineers newly employed during 1968	1,845	39
Total full-time engineering technicians employed during 1968	59,907	3,056
Number of additional engineers immediately desired	3,437	200
Engineers leaving for reasons of retirement or death during 1968	755	26
Engineers leaving for reasons other than retirement or death	1,525	31
Engineers eligible to retire from highway departments within the next 5 years	2,985	200
Number of additional engineers needed by highway departments within the next 5 years	8,431	
Number of additional engineers wanted by contractors within the next 5 years	23,300	
Number of additional engineers needed by cities, counties, federal government, and other industries within the next 5 years	?	

The number of degrees in civil engineering granted by all U. S. colleges in 1968 was 5,446 bachelor's degrees, 2,206 master's degrees, and 416 PhD degrees.

THE CHANGING RESPONSIBILITIES OF THE HIGHWAY ENGINEER

Part of the problem of retention of engineers in highway departments is the rapidly changing picture of the responsibilities of highway engineers. The continuously increasing capacity and complexity of construction equipment, with a resulting increased speed of construction, are placing ever-increasing responsibilities on engineers engaged in construction administration for speedy and correct decisions. The greatly increased volume of highway work combined with the shortage of engineers in the employment of the highway departments is also causing many highway departments to change from the practice of doing all of their own planning, design, and construction engineering to the practice of employing consulting engineers for design and of requiring contractors to do their own construction control. These practices do not decrease the total number of engineers needed by the highway industry; they only shift the responsibilities. If anything, they increase the technical competence needed by state highway engineers.

THE STUDY

The decision that an engineer makes in accepting employment with any organization or his decision whether or not to remain in the employment of that organization is based on opinions. Hence, our study of factors affecting these decisions was in the nature of identifying and evaluating the elements on which these opinions are based.

Our approach to this study of factors affecting the opinions of engineers was first to interview some 20 young engineers who had left the Ohio Department of Highways within the past few years and who were now in positions of responsibility, thus indicating that they were qualified engineers. The opinions expressed by these engineers were summarized and organized into a questionnaire that was then sent to some 300 engineers who had left the Ohio Department of Highways within the past 10 years. In an attempt to make sure that we would detect any peculiarities in the Ohio situation relative to the retention of engineers, similar questionnaires were sent to some 300 engineers who had left 4 other state highway departments in the same period. The group, including Illinois, Indiana, Kentucky, and Minnesota, is identified as our control group. The many reasons given by engineers for leaving highway departments are summarized and evaluated, and recommendations are made on steps that could be taken to alleviate the situations that had caused these decisions.

A second major phase of the study was to look into the factors affecting the attraction of newly graduated civil engineers to the department of highways. Here again, through questionnaire and interview, all seniors in civil engineering in the 10 schools in Ohio offering a bachelors degree in civil engineering were questioned and stated opinions summarized. A disturbing factor learned through these questionnaires was the very low percentage of civil engineering graduates who indicated that they had received encouragement from their university faculties to accept employment with the department of highways.

The more important observations made from the information gathered and the conclusions reached therefrom are given in the remainder of this paper. The organization is similar to that of the full report of the study where supporting information is given for the statements made here.

RETENTION OF COMPETENT ENGINEERS IN STATE HIGHWAY DEPARTMENTS

1. Cost of losing engineers. Loss of professional engineers after several years of employment in any organization is costly to the organization. Costs can be measured in terms of loss of efficiency in production until new men are trained to replace those who left, loss of the invested time and money for training the engineer who left, and cost of training the new replacement.

2. Length of service. Our study shows that of the engineers who left the Ohio Department of Highways, 17 percent left within 1 year and 55 percent left within 3 years of their starting employment.

3. Value of summer employment during college in motivating engineers to remain with state highway departments. Of the engineers who left the Ohio Department of Highways during the 10-year study period, 41 percent had not been employed by the department during summer vacations before graduation from college. Summer employment of engineering students can be used to motivate interest in the highway industry as a career. It is essential, however, that the engineering students be employed in engineering work and that this work be challenging. It is apparent that unless the supervision of engineering students who are employed for summer work is good, the results may be negative motivation.

4. Engineering graduates from outside of Ohio. Of the engineers who left the Ohio Department of Highways during the study period, 38 percent were graduates from colleges outside of Ohio. It is probable that many young engineers take a job only to get a few years of experience, with the full intention of then leaving that job to return to their home state for permanent professional careers. This is especially true if these young engineers have strong family ties that are an inducement to return to their original homes.

5. Intent of engineers to stay with the state highway department. Eighty-one percent of the engineers who left the Ohio Department of Highways and 76 percent of those from the control group (Illinois, Indiana, Kentucky, and Minnesota) indicated that when they first accepted employment with the state highway department, they fully intended or at least they had open minds regarding the decision, to make such employment a career.

6. Reasons for accepting first employment with the Ohio department of highways. In answer to the question as to what most influenced them to first accept employment with the Ohio Department of Highways, the engineers most often listed the following: (a) engineer-in-training program sounded good, (b) interesting and challenging work, (c) best job available in location where I wanted to work, and (d) opportunity for engineering experience.

7. Misgivings about accepting employment with state highway department. In answer to the question as to what misgivings, if any, they had concerning acceptance of their

first employment with a department of highways, engineers both in Ohio and in the control group, listed the following most often: (a) appeared that politics might influence opportunity for advancement and (b) low salary.

8. Engineer-in-training program. Information from engineers who had left the highway departments indicated that only a very few had originally entered employment through a good orientation or engineer-in-training program.

9. Reasons for leaving state highway department. In an effort to determine the relative importance of the many factors that had a bearing on an engineer's decision to leave the employment of state highway departments, we listed a number of obvious reasons. The men were asked to rate these, giving 10 points for the most important reason, 9 for the second most important, and so on to 0 for the several least important reasons. The number of factors listed most often, both in Ohio and in the control group, were respectively as follows: (a) long-range advancement possibilities looked poor, (b) opportunities for advancement too much influenced by politics, (c) salary was too low, (d) type of work was not challenging, and (e) work assignment did not allow opportunity for use of engineering judgment.

ATTRACTING NEW CIVIL ENGINEERING GRADUATES TO THE OHIO DEPARTMENT OF HIGHWAYS

1. Education beyond the bachelor's degree. When interviewed, the majority (48 out of 85) of senior civil engineering students in Ohio colleges indicated that, after receiving their bachelor's degree in civil engineering, they desired to continue their formal education. Twenty-nine indicated that they wanted to take advanced work in civil engineering, 10 in business administration, and 5 in law.

2. Attitude of students toward summer work with the Ohio Department of Highways. In response to the inquiry as to which summer work experience had the most appeal to them, engineering students gave the following answers most frequently: (a) doing challenging work, (b) having opportunity to use engineering knowledge, (c) having responsibility, and (d) gaining practical experience. Of those who had worked at least one summer with the Ohio Department of Highways, 47 percent thought that they were confined to routine jobs that offered little challenge, a minimal chance to demonstrate engineering ability or responsibility, and poor opportunities for gaining worthwhile experience.

3. Recruiting college sèniors in civil engineering. Although 58 percent of the college seniors, when filling in our questionnaire in March or April, 1968 indicated that they expected to graduate in June of that year, only 15 percent, at that time, had accepted employment. Only 23 percent said that they had been offered employment by the Ohio Department of Highways.

4. Factors important to a college graduate in selecting first employment. A most important decision in a young man's professional life is the selection of his first job out of college. In our questionnaire, students were asked to list the factors that had most affected their decision. In the order of number of times listed, the most important factors were (a) challenging work, (b) prospective pay increases and promotions (c) opportunity to increase knowledge by experience, (d) starting salary, (e) opportunity to use engineering judgment, and (f) long-range advancement opportunities. It is observed that retirement benefits and probability of military draft deferment due to occupation were well down in the list of factors considered by the students, being respectively No. 14 and No. 16.

5. Formal in-service training programs. Eighty-two percent of the senior civil engineering students indicated that they preferred to start their professional engineering carrer in a formal in-service training program.

6. Advice from college instructors concerning employment with state highway departments. Only 22 percent of the senior-year students indicated that their college professors had encouraged them toward any interest in employment with the Ohio Department of Highways. Perhaps an important aspect of this attitude is that some college faculty members who teach highway engineering courses admit knowing very little about the Department of Highways.

7. Starting salaries for civil engineers. Although the starting salaries offered by industry (all employers except government agencies) to civil engineers with a bachelor's degree from the Ohio State University has held fairly close to the average starting salaries for all engineers for the past 10 years, the starting salaries offered by the Ohio Department of Highways has lagged considerably behind salaries offered by industry.

8. Starting salaries offered by state highway departments. As of January 1, 1969, the starting salaries offered by all state highway departments for an engineer with a bachelor's degree in civil engineering averaged $8,312. The reported range was from $7,272 to $9,624 (excluding Puerto Rico); Ohio's figure was $7,904. Ohio, however, reports that a graduate may start at $8,736 if he has passed the written examination for his EIT certificate.

MANPOWER UTILIZATION IN STATE HIGHWAY DEPARTMENTS

1. Need for adequate manpower planning. The very critical shortage of engineering personnel that the Ohio Department of Highways, as well as many other state highway departments, now faces, reflects the fact that manpower planning has not received the serious consideration that it deserves.

2. Dollar investment in manpower. As a national average, one-fifth of the money spent for highways goes into salaries of employees, including engineers, engineering technicians, administrators, and other related personnel. Good manpower management dictates that every effort must be made to motivate these personnel to the highest possible productivity and to encourage them to remain in the organization.

3. Anticipated retirement of engineers. Figures reported from Ohio indicate that approximately 29 percent of the present engineering staff will be eligible to retire within the next 5 years. In addition, the persons who will leave the service because of disability, death, or other reasons makes the problem of shortage of engineers very critical.

4. Total manpower needs. The number of engineers and engineering technicians employed by the states is affected quite considerably by the practices employed with regard to the states performing its own design work versus having it done by consulting engineers, and of doing its own construction control surveying versus requiring contractors to do it. In 3 states, who do all of their own highway design work, the average number of engineers employed was 4.6 per million dollars worth of construction work. Ohio's figure of 680 engineers for a $460,000,000 construction program averages only 1.5 engineers per million dollars worth of work. From available figures, it would appear that the total number of engineers employed by all state highway departments and by consulting engineers on highway design work is approximately 34,000.

A state department of highways cannot solve its problem of shortage of engineers and engineering technicians by turning more of the engineering work over to consultants and contractors. Although shifting of these responsibilities to consulting engineers and contractors reduces the number of engineers required by the department of highways, it does not reduce the quality of engineering needed. In fact, a more competent engineer is required to thoroughly and accurately review a set of plans prepared by someone else and to determine that the design is adequate and economical than to "start from scratch" and design a complete project. The highway department needs many top-quality engineers on its staff.

5. Control surveying for engineering construction. Ohio is now requiring the contractors to do a very large percentage of their own control surveying work for construction, furnishing the contractors only with centerline and bench marks. It is more difficult to detect errors in surveying made by another field party than it is to avoid making errors. Consequently, the state highway department must have on its construction projects engineers who are thoroughly familiar with construction projects and who know where and how to check for possible errors or mistakes.

6. Effect of politics in recruitment and promotion of engineers in the state highway department. A high percentage of the engineers who have left the Ohio Department of Highways and likewise of senior-year civil engineering students in Ohio colleges, when voicing reasons why they would not choose to work with the Ohio Department of Highways,

expressed the opinion that politics play too much of a part in the advancement and promotion of engineers.

Because public works projects, such as highways, are paid for by the taxpayers, it is necessary that the administrative head of the highway department be responsible to the public. This is done in all states by having the policy-making person, or persons, in the highway department responsible to an elected official, usually the governor. Thirty-nine states reported that their highway departments are administered through a commission whose members are appointed by the governor. A majority of these commissioners are appointed for terms of 6 years or more and appointed for overlapping terms. In such state highway departments, the engineering personnel are generally free from direct political pressures. The number of positions in the upper echelon of highway departments, filled directly by appointment by the governor, varies from 40 in 1 state, 19 in 1 state, 18 in 1 state, 9 in 1 state, and 1 in each of 13 states. Ohio has 19 men whose positions depend directly on appointment. This observation is in no way intended to imply that the engineers occupying the top 19 administrative positions in the Ohio Department of Highways are anything less than top quality. In Ohio, the present director of highways came out of early retirement, after a full professional career in the highway department. And, if in another election the opposite political party came into power, there is no reason to doubt that competent men would be named to replace those who now occupy the appointive positions. However, the problem insofar as attraction and retention of engineers in the department of highways is concerned, is that young engineers realize that their opportunities for advancement to top positions may depend, to some extent, on politics rather than on demonstrated engineering ability.

7. Analysis of highway administrative organization. The purpose of this study is not to analyze the organization and administrative procedures of the Ohio Department of Highways.

8. Training men for professional engineering competency. A certain percentage of young engineers admit accepting employment with the Ohio Department of Highways primarily for the purpose of obtaining experience that would aid them in obtaining their Ohio professional engineer's license. After this period, they seek employment with contractors, consulting engineers, or other segments of the engineering industry.

FORMAL IN-SERVICE TRAINING PROGRAMS FOR HIGHWAY ENGINEERS

1. Inadequacy of the 4-year bachelor of civil engineering program. Although it is generally agreed by employers of new engineering graduates, by educators, and by professional societies such as the American Society of Civil Engineers that 5 years is needed to obtain a professional engineer's education, the law of supply and demand is effectively forcing schools to provide a program that will allow a student to obtain a bachelor's degree in civil engineering in 4 years. In the 4-year program there is little room for practical courses of application of theory to engineering design or construction problems. To make newly graduated engineers productive, it is necessary for the employer to provide the kind of practical training that the engineer has not received in college. Such training programs will be most effective if organized as formal orientation or in-service training programs.

2. What a formal in-service training program for highway engineers should include. The subject of orientation programs was discussed in considerable depth with the directors of training programs that have been known to be successful in several states. From these discussions, certain observations were made that can be considered as essential for a good program. These include the following: (a) program should continue 24 months; (b) success of the program will vary directly with the quality of administration, leadership, and direction; (c) program should be planned, supervised, and continually monitored by an advisory committee; (d) goals to be accomplished in each phase of the training program must be spelled out specifically so that they are understood in advance by the trainees as well as by the trainers; (e) trainees should be assigned to supervisors in the field who are sympathetic with the aims of the program; (f) the manner in which an individual is initially greeted, made to feel a part of the organization, and oriented has a significant

influence on whether he continues as an employee of the state or resigns; (g) uniform methods and intervals for an evaluation of the trainee's progress should be established; (h) early in the program, an orientation session of 2 or 3 days should be held in which all new trainees are brought together for a series of lectures and seminars; and (i) a formal ceremony should mark the completion of the engineer-in-training program with appropriate recognition and, possibly, the awarding of certificates.

3. Productivity while in training. It is desirable for engineer trainees to be used in productive work as much as possible without diluting or hindering the primary purpose of the program, which is to prepare the new engineers for the assumption of positions of responsibility in the highway department. A fairly large percentage of the trainee's time should be spent on projects in which he is actually producing, or "learning by doing." It is essential, however, that this practical experience be supplemented by and coordinated with a classroom type of schooling. The lecture sessions are fundamental to make sure that trainees thoroughly understand what is going on in the field and why things are done in the way they are. The classroom-type schooling sessions can generally be planned to coincide with times when the trainees are scheduled to be in the central office of the department of highways. Here, organized classes can most easily and effectively be conducted.

4. Advisory committee for continuing education. The in-service training program for a state the size of Ohio is too important, big, and costly to be administered by one man. The training director needs not only staff assistants but also cooperation from all segments of the highway department. To afford guidance to the training director and his staff in the preparation and conduct of all phases of the course, it is recommended that an advisory committee be created. The committee should include representatives of the several sections of the highway department that are most concerned, including the director's office, design, construction, and operations, and a representative from outside the highway department in the education profession. This is the pattern observed in several state highway departments whose training programs have proved to be most successful.

5. Trainee counseling and evaluation. It is important, for several reasons, for the training director to keep in touch with, and be aware of, the progress being made by each trainee.

6. Other programs of continuing education in the department of highways. Engineering technicians, inspectors, project engineers, maintenance supervisors, and practically all other employees of the Ohio Department of Highways need to continue their education. This subject is covered in the next section.

OPPORTUNITIES FOR CONTINUING EDUCATION AND PROFESSIONAL DEVELOPMENT IN THE STATE HIGHWAY DEPARTMENT

1. Keeping up with new knowledge in engineering. New engineering knowledge applicable to road building is increasing at such a rate that it is estimated to be doubling approximately every 10 or 12 years.

2. Participation in continuing education programs. Our survey showed that many states are providing opportunities for engineers to continue their education. Thirty-three percent of the state highway departments report that they make a practice of giving selected engineers time off, with partial or full salary, to carry additional college courses. In 85 percent of the highway departments, the practice is to give time off, with full salary, to attend local, professional technical meetings. Seventy-seven percent of the states allow such time off for attending national meetings.

3. Communication of new knowledge to men who can use it. Generally, only top echelon engineers of most departments of highways are able to attend national technical professional meetings. The information and new knowledge that these top men learn at such meetings and the papers they acquire are of little value unless passed on to the men who can use this new knowledge. Better channels for communication of new knowledge should be established. The annual Ohio Highway Engineering Conference serves as one type of channel. At this conference, reports on new developments in highway engineering, which may have been released by a national organization such as the Highway

Research Board, can be repeated at the local conference, where many younger engineers, who do not attend the Highway Research Board meeting, can hear the presentation. This channel of communications could be improved if all engineers-in-training and other young engineers with the Ohio Department of Highways were required to attend the annual Ohio Highway Engineering Conference and to read papers that are included in the Conference Proceedings.

4. Formal continuing education classes. Another, and perhaps even better, channel of communication of new knowledge to younger engineers would be through formal classroom sessions held as part of the engineering-in-training programs. These formal, in-service refresher courses might best be conducted on specific subjects such as earthwork construction, drainage, portland cement pavements, or bridges. These courses will be of little value unless the teaching effort is well organized, the material is good and well illustrated, and the lectures are well presented.

5. Lecture courses for technicians. Courses for engineering technicians, mostly construction inspectors, could be held for a divison or for a group of divisions.

6. Personnel administration seminars for all men in supervisory positions in the state highway department. A course in personnel administration was set up by the Department of Civil Engineering in 1961 for highway administration personnel of the Ohio Department of Highways. This course was repeated several times for groups of administrative personnel in 1961 and 1962. More recently, similar courses have been conducted by the College of Administrative Sciences.

7. Financial support for additional college education. Many state highway departments and the U. S. Bureau of Public Roads have a practice of selecting a few young engineers who show outstanding promise and giving them a term or full academic year of leave of absence for college work toward an advanced degree. These grants usually include an understanding that the employee will return to his previous employer for a minimum specified period of years.

8. Sponsored research at universities. The Ohio Department of Highways, with the assistance of the U. S. Bureau of Public Roads, has been most generous in sponsoring research at universities. Benefits from this program include development of much new knowledge. In addition, this research also develops the interest of many bright young engineers in highway problems and helps the faculty to acquire a better understanding of highway engineering.

ADEQUACY OF UNIVERSITY CURRICULA IN PREPARATION OF CIVIL ENGINEERS FOR EMPLOYMENT WITH STATE HIGHWAY DEPARTMENTS

1. Decreasing number of engineering graduates produced annually by universities. While total college enrollments since 1959 have increased approximately 40 percent, enrollments in engineering have increased less than 3 percent. The period of this drop in enrollment in engineering coincides exactly with the period of changed requirements for accreditation by the Engineering Council for Professional Development (ECPD). Under these requirements, engineering curricula, in order to be accredited, are required to include more science, mathematics, and humanities, and consequently a reduced amount of time spent in courses dealing with practical applications of engineering knowledge.

2. Makeup of civil engineering curricula. The ECPD is governed largely by chemical and electrical engineers, and, under present regulations for accreditation of colleges, this accreditation committee is looking primarily at science-oriented courses. Engineering colleges, forced to graduate men with a bachelor's degree in 4 years, are of necessity making up a 4-year program almost entirely of basic sciences, mathematics, and humanities, with very little course work in practical application of engineering knowledge.

3. Prerequisites for university faculty positions. Under present trends, most engineering college deans seem to feel that all staff members must have PhD degrees. This attitude is contrary to recommended policies of such highly respected organizations as the American Society of Civil Engineers, which is on record as expressing the opinion

that a good and well-balanced faculty should include some members who are engineers with practical experience, irrespective of the degree obtained.

4. Education supplementary to the 4-year bachelor of civil engineering program. It is quite probable that the 4-year program for a bachelor of science degree in civil engineering will be continued in most schools. Even Ohio State University is dropping back from a 5- to a 4-year program. This means that the employer of new college graduate engineers must provide for the continuation of the education needed by the new graduates by providing for them the practical know-how needed to do professional engineering.

CO-OP PROGRAMS, SUMMER EMPLOYMENT, AND UNDERGRADUATE SCHOLARSHIPS FOR CIVIL ENGINEERING STUDENTS

1. Full-time summer work for college students. The summer vacation period for college students generally coincides with the time of the year when construction volume is at a peak. Hence, the use of engineering college students as temporary employees of the state highway department for construction inspection is a natural procedure and is beneficial to both the students and the department.

2. Factors affecting an engineering student's choice of field of specialization. The first year's curriculum in most branches of engineering is so similar that many students do not definitely pick their field until the beginning of the second year of college. If engineering students are employed by the department of highways during the summer vacation following their freshman year, the state has an opportunity to encourage these young men to choose highway engineering. To be favorably impressed, the student must find his work interesting, challenging to his ability, varied, and satisfying through a sense of accomplishment.

3. Orientation course for engineering students completing freshman year at Ohio State University in preparation for summer employment as construction inspectors with the Ohio Department of Highways. This program, conducted by the Department of Civil Engineering of Ohio State University, attracted 183 students in 1966, 110 students in 1967, 136 students in 1968, and 101 students in 1969. A large majority of the students who took the orientation course have indicated that it gave them adequate preparation for their summer work as construction inspectors with the Ohio Department of Highways. This was the primary goal of the course. From conversations with several of our present third-, fourth-, and fifth-year civil engineering students, we have reason to believe that the orientation course and a satisfying summer experience as an inspector with the Ohio Department of Highways were influential in their decision to choose civil engineering as the branch of engineering for their college work and to major in highway engineering. The annual orientation course should be continued.

4. Part-time work during the academic year. Many undergraduate students at Ohio State University work part-time during the regular school year and full-time during vacations in central offices of the Ohio Department of Highways such as the Bureau of Bridges, Bureau of Location and Design, Materials Testing Laboratory, Aerial Photogrammetry Section, and Planning Survey. Supervisors of these young men and women are in positions to cultivate their interest in the Ohio Department of Highways as a place for permanent employment after graduation.

5. Full-time work for a given term such as co-op programs. In the University of Cincinnati's co-op program with the Ohio Department of Highways, a total of 103 students are reported to have participated from 1946 to 1967. As far as can be learned, only 11 of these students have remained with the Ohio Department of Highways. The factors that are appealing or discouraging to co-op students in working with the Ohio Department of Highways are substantially the same as those described earlier for engineering students working during summer vacations from other colleges.

6. Undergraduate scholarship programs. The scholarship program for civil engineering students at the University of Kentucky, sponsored by the Kentucky State Highway Department, has been continuously successful since 1948.

ATTRACTING YOUTH TO STUDY ENGINEERING

1. The state's responsibility for the education of engineers. Part of the problem of the shortage of civil engineers available to state highway departments is the total shortage

of students studying engineering in colleges now and during the past several years. The percentage of students in college who are choosing engineering seems to be decreasing every year.

2. Awareness of the work of the professional engineer. Part of the problem is the lack of awareness of a large percentage of the general public as to what an engineer is or does. A reliable poll showed that less than 6 percent of the public is aware of the work of the professional engineer.

3. High school preparation for studying engineering in college. Possibly one factor that is causing a reduction in the number of students who choose engineering when entering college is that they have not been prepared in high school to face the discipline required to study engineering. Many youths, even though they have a high school diploma, have failed to take the necessary mathematics and science courses that are prerequisites to the study of engineering in college.

4. The industrial arts curriculum project at Ohio State University. An attempt is being made in the College of Education at Ohio State University to develop at the junior high school level a course of study that will create an awareness among pre-high school students of engineering construction as a profession. This course, now being taught in many junior high schools, is called "The World of Construction."

EMPLOYMENT AND TRAINING OF ENGINEERING TECHNICIANS FOR THE DEPARTMENT OF HIGHWAYS

1. Need for more and better trained engineering technicians. Because of the present and anticipated continuing critical shortage of engineers, the state must plan to have more of the subprofessional engineering work done by engineering technicians.

2. Improving the capabilities of currently employed engineering technicians. Many engineering technicians now employed by departments of highways are not producing to the maximum extent of their capabilities. The technicians can generally be classified into 3 groups: (a) beginners, (b) men with 1 or 2 years of practical experience, and (c) experienced technicians who might be prepared to assume more responsibility in work such as construction project administration, design, and materials testing.

3. In-service training courses for engineering technicians now being conducted in other states. Practically every state highway department is making some effort toward providing continuing education for engineering technicians. The extent of the effort and the results vary a great deal. The programs of several states, including Alabama, Georgia, Indiana, Illinois, Kentucky, Michigan, and Virginia, were studied and found to have different approaches to the problem of training technicians. Details of the programs of these states are included in the full report.

4. Instructors for continuing education courses conducted by a state highway department. Many state highway departments use engineers and other departmental personnel as instructors in winter short courses for construction inspectors.

5. Preparatory education of highway engineering technicians in technical institutes. In several states, the department of highways is working closely with established technical institutes or junior colleges in conducting a 2- or 3-year program leading to a certificate of civil engineering technology. The content of the several programs examined are quite similar. The program being followed by the Michigan Technical Institute is shown in detail in the full report. According to the best information available, Ohio now has 8 technical institutes offering certificates in civil engineering technology, and several more institutes are in the process of being formed.

6. The program of the Illinois Division of Highways for training engineering technicians. For the past 12 years, Illinois has conducted a 10-week orientation course each summer for high school graduates who are selected on a competitive basis to prepare them for full-time employment as engineering technicians with the Illinois Division of Highways. This couse has been very successful from many points of view: (a) Sixty-two percent of those who have taken the technician course are still employed with the Division of Highways; (b) another 13 percent are on military leave; and (c) 12 percent have left the Division of Highways to return to college to study engineering, and many of these undoubtedly will return to the Division of Highways as engineers.

CONTRACTORS' USE OF CIVIL ENGINEERS AND TECHNICIANS

1. Employment of engineers and engineering technicians by contractors. One of the biggest benefits of the competitive-bid system of highway construction is that the contractors are always searching for better and less expensive ways of doing a satisfactory job. This means that they are looking for the kind of thinking usually found in qualified civil engineers and engineering technicians. The increasing demand for civil engineers by contractors further reduces the number available to state highway departments.

2. Number of civil engineers and engineering technicians now employed by contractors. The construction industry in the United States is big and is getting bigger. For the year of this study, figures reported by Engineering News-Record indicate that the total work done on competitive-bid private contract basis on highway, heavy municipal, and utility projects totaled $33.3 billion, industrial building construction totaled $18.1 billion, and residential building totaled $23.5 billion, for a grand total of $74.9 billion. The size and ever-increasing sophistication of machines used in engineering construction is such that there is an increasing demand for engineers and engineering technicians to be employed by contractors.

3. College graduates currently employed by general contractors. Figures from our sample study indicate that large general contractors employ an average of 1.185 college graduates per million dollars of work annually; of these, 0.775 are civil engineers. Small general contractors have 1.526 total college graduates and 0.768 civil engineers, and building contractors have 0.890 total graduates and 0.384 civil engineers per million dollars worth of work. Applying these figures to the total construction program for the year of our study indicates that large general contractors employed a total of 20,000 civil engineers; small general contractors, 5,600 civil engineers; and building contractors, 7,000 civil engineers, for a total of 32,600. This is an appreciable number of engineers when compared with 27,273 engineers currently employed by all state highway departments.

4. Additional engineers to be needed by contractors. Our study indicates that contractors will need additional engineers as follows:

Contractor	Within 5 years	Within 10 years
Large general	11,200	27,500
Small general	6,400	10,200
Building	5,700	11,300
Total	23,300	49,000

5. Engineers used by contractors as project supervisors. Information from our sample study indicates that large general contractors employ an average of 1.26 supervisors per million dollars worth of work annually and that 27.6 percent of these supervisors are engineers; thus, the total number of engineers used as supervisors in 1968 was 9,050. Small general contractors used 1.95 supervisors per million dollars worth of work, of whom 13.8 percent were engineers, or a total of 1,960 engineers. Building contractors used 1.42 supervisors per million dollars worth of work, of whom 12.8 percent were engineers, making a total of 3,290 engineers.

6. What contractors want in preparatory education for engineers. A survey conducted by AGC indicated that most contractors prefer that an engineer have 5 years of college, including all of the basic courses of civil engineering having to do with a knowledge of materials and design and additional courses in personnel management, labor relations, accounting, and economics.

7. Starting salaries offered to engineers by contractors. Large contractors reported offering to civil engineering graduates a minimum starting salary of $8,000 per year, a maximum of $12,000, and an average of $9,100. Small contractors offered a starting minimum of $6,000, a maximum of $10,000, and an average of $7,700. Building contractors offered a starting minimum of $5,000, a maximum of $8,000, and an average of $7,300. By comparison, the starting salaries offered civil engineers with bachelor's degrees by state highway departments, as reported earlier were minimum $7,272, maximum $9,624, average $8,312.

8. Engineering technicians employed by contractors. Large general contractors indicate that they are currently employing 4,450 engineering technicians and within the next 5 years would like to employ an additional 8,900. Small general contractors now employ 4,230 and within the next 5 years would like an additional 10,360. Building contractors now employ 2,930 engineering technicians and within the next 5 years need an additional 12,560.

9. Salaries paid civil engineering technicians. Beginning salaries offered to civil engineering technicians by large general contractors average $8,900 per year; small general contractors, $7,500 per year; and building contractors, $6,500 per year.

10. Continuing education for construction engineering technicians. In several states, contractors' associations, with the support of universities, are holding short courses and workshops during the slack construction season for employees of contractors at the supervisory and foreman level. These courses cover a variety of subjects from general understanding of plans and specifications to special courses in specific areas of work such as flexible pavements, rigid pavements, bridges, and earthwork.

SUMMARY OF RECOMMENDATIONS

The information presented here as observations and conclusions can be further summarized in the form of recommendations as follows:

1. The problem of attraction and retention of engineering talent by a department of highways has so many and such diversified identifiable aspects that it is beyond the capability of one person to fully analyze, much less to solve. It is recommended that an advisory committee on education and training of personnel be established within each department of highways. States that appear to have been most successful in their programs of retention of competent engineers have such committees with a membership that includes not only several persons from the department of highways but, in every case, representatives from the state's civil service commission and the leading state university.

2. The director of personnel training and his staff, working with the advice and counsel of the advisory committee, should initiate several actions as follows:

   a. Secure reasonable guarantees to ensure that engineers are used as engineers, are allowed to use their professional judgment, and are assigned to challenging work.

   b. Provide opportunities for continuing education for present engineers. This can be accomplished by conducting in-service training courses and by providing encouragement and financial support for qualified engineers who desire and opportunity to further their college education in highway-related fields of study.

   c. Provide orientation or engineer-in-training programs for new engineers with the department. Time spent with the individuals in this orientation program, making sure that each is motivated to develop professionally as rapidly as possible, will be a good investment. Recognizing that college graduates from 4-year programs will have had very little preparation for practical professional engineering work, those responsible must carefully design the in-service training program to provide this training.

   d. Provide in-service training programs whereby a fairly large percentage of the trainee's time is spent in productive work where he will be learning by doing. The training program must, however, include classroom sessions on theory of design, intent of specifications, testing of materials policies, and procedures of the department.

   e. Arrange for engineers who are in the engineer-in-training program to attend the annual Ohio Highway Engineering Conference. Trainees should be furnished copies of the proceedings of these conferences and be assigned homework and quizzes on the content.

   f. Take an interest in the teaching of civil engineering in all colleges in the state and assist these colleges in doing a better job of preparing men for work in the highway industry.

g. Select a few top-quality young engineers and give them encouragement, including financial assistance, to pursue advanced college work with the provision that they will return to the highway department to put their new knowledge to work.

3. Several steps can be taken to attract more engineers to the Ohio Department of Highways. These include the following:

a. The Spring Quarter Orientation Program for Freshmen at the university should be continued as desirable preparation for summer employment with the department. Engineers who take the course should be rewarded, possibly with some slightly increased salary over that paid to freshmen who have not taken the course. The engineers who complete this orientation program must be used in meaningful and challenging engineering work. Otherwise, they will be lost to the department as potential full-time employees.

b. All state highway departments need to assist, in every way possible, the creation of a better public image of the highway engineer. This can be done through providing assistance programs of education at the junior high school level and by aiding state high school vocational guidance counselors in knowing more about highways.

4. As the state is forced to use an ever-increasing number of engineering technicians in subprofessional engineering work, programs should be designed to give needed education and training to new engineering technicians and to provide refresher courses for practicing engineering technicians. Efforts should also be made to assist the various technical institutes in the state to do a better job of preparing civil engineering technicians.

5. Manuals for construction inspectors are needed. These manuals should be prepared in a language that is understandable to the technicians and should be published in a manner that will allow updating as new knowledge is developed and specifications are changed.

6. Ohio should recognize that the practice of allowing consulting engineers to prepare plans and of requiring contractors to do their own location control means that these 2 groups are going to need more engineers and engineering technicians. The state has an opportunity, and perhaps even a responsibility, to assist in the preparation of qualified engineers and engineering technicians for contractors and consulting engineers.

7. The key to a continuing good state highway department is the continual upgrading of the capabilities, knowledge, and skills of the employees of the department.

Discussion

KERMIT BERGSTRALH, Roy Jorgensen and Associates—Professor Karrer's paper represents needed research and good research. The data may indicate something other than a critical shortage of engineers in the state highway departments, but the data are valuable. Using Professor Karrer's data, it seems reasonable to conclude that some highway departments may be overstaffed with engineers and may be using graduate engineers as substitutes for intermediate and advanced technicians. He reports that the state highway departments employed 59,907 technicians and 27,273 engineers in 1968—about 2.2 technicians per engineer. The data also show that Ohio, the only individual department on which employment information was included in the report, employed 3,056 technicians and 680 engineers in 1968—about 4.5 technicians per engineer.

Work sampling techniques have been used to identify the percentages of the bridge design, road design, and construction inspection work loads that require the employment of engineers. The results of these studies vary, but roughly 25 percent of the bridge design work, 15 percent of the road design work, and 10 percent of the construction inspection work apparently must be performed by engineers. These data fluctuate somewhat according to the methods used to perform the design and inspection work, and according to the extensiveness with which computers are used, but few engineers would place more than 20 percent of the inspection work or more than 30 percent of the design work in the engineering classification.

More than 30 percent of the technical positions in the state highway departments were filled with engineers in 1968, according to Professor Karrer's report.

Graduating engineers gave Professor Karrer many reasons for accepting highway department employment. These 5 reasons were included among the 6 shown in his report:

1. Challenging work,
2. Prospective pay increases and promotions,
3. Opportunities to increase knowledge by experience,
4. Opportunities to use engineering judgment, and
5. Long-range advancement opportunities.

The following 4 reasons were among the 5 listed as the reported reasons for resignations:

1. The work was not challenging,
2. Salaries were too low,
3. Work assignments did not offer opportunities for use of engineering judgment, and
4. Long-range advancement opportunities looked poor.

The real shortage of manpower in the highway departments, if recent work analyses and staffing analyses are correct, is in the advanced technician groups. Nearly 60 percent of the design work requires the employment of well-trained, highly experienced technicians. Although many individual construction inspection assignments can be performed by technicians with limited training and experience, the varieties of those assignments and the ways work loads change on construction projects require the employment of well-trained, highly experienced technicians—or the employment of additional numbers of technicians with limited training so that inspectors capable of doing different kinds of work will always be available when each type of work must be performed. Apparently, if the percentages of intermediate and advanced inspection technicians can be increased, the total numbers of inspectors employed can be reduced, within reasonable limits.

The reasons given for resignations indicate that engineering graduates are being used as substitutes for intermediate and advanced technicians. Obviously, graduate engineers should be given engineering assignments, but this can be very difficult to do. Project design engineers faced with work loads and deadlines must assign the work to personnel capable of doing the work. If adequate numbers of advanced technicians are not available, engineers must be used as substitutes.

Highway departments are having difficulty keeping trained and experienced technicians for 2 principal reasons.

1. As the work to be performed becomes more complex, the numbers of advanced technicians employed must be increased. But the personnel classification specialists find it difficult to increase consistently the percentages of the technician positions allocated to the higher technician classifications. Work analyses show that this must be done, and, when statistical data are collected to prove this point, the classifications usually are changed. Undocumented assurances of the needs for additional advanced positions are not enough.

2. The salary levels of the advanced technician classifications—and of almost all advanced personnel classifications—typically are below the prevailing rates. Entrance salaries usually are equal to or relatively close to going rates, but the funds available for salaries are too limited to permit the payment of prevailing rates to all personnel.

Walter Hjelle, Commissioner of the North Dakota Department of Highways, submitted another paper to the Highway Research Board this year. Commissioner Hjelle reports that his department has adopted a prevailing rate salary plan for all classifications of employment and has financed the essential increases by reducing the numbers of persons employed. The turnover of engineers was reduced from 20 percent to 8 percent as a direct result of the improved salaries.

When salaries are low, the advanced technician and engineering personnel typically receive salaries considerably more out of line with the competition than do the entrance-level personnel. When advanced positions are vacant, additional numbers of entrance-level positions are created and filled. This results in overstaffing with persons who are unable to do advanced technician work, and with graduate engineers who must get the technician work done.

Commissioner Hjelle has suggested an approach that not only is logical but should be fully practical: Determine, by research, the numbers of persons needed at each level of employment to accomplish the essential work, using modern work methods. Identify the salaries being paid by major employers for the needed levels of employment. Employ the numbers of persons needed at the salary levels being paid in the labor markets. Pay the employees for performance and not for years of education and years of experience completed.

As indicated earlier, Professor Karrer's data are valuable. They point up a critical problem in manpower management. Before steps are taken to increase the numbers of engineers employed, however, it should be worth the effort to find out if the engineering work to be done is equal to or in excess of the numbers of engineers employed. Engineering assignments cannot be created without engineering work loads. If managers who are hard pressed to get the work done cannot provide challenging work assignments to the currently employed engineers, there is reason to doubt the need for additional engineers.

Kansas Equipment Development Program

LaRUE DELP, State Highway Commission of Kansas

•SEVERAL YEARS AGO, Kansas started reorganizing all facets of its highway maintenance program toward the principal objective of total mechanization, thereby eliminating all hand work. This program would provide a "machine-tooled" finish for all repairs. Because most work is accomplished under traffic conditions, the new mechanized equipment should be maneuverable and should be equipped with the latest accepted safety features. Equipment development was to be accomplished on a team project basis, utilizing personnel of the Research Department. The Maintenance Department was to assign each problem, state each objective, and furnish all labor and materials. The Research Department was to direct the work and record the results.

PLANNING

Equipment was a major factor considered in determining the size of a maintenance unit. We knew from experience that, with a well-planned repair and resurfacing program, 1 crew could maintain approximately 100 two-lane miles under normal weather and traffic conditions in Kansas. Also, properly balanced, most equipment could be assigned a dual role: its prime function plus storm coverage throughout the winter months. Such equipment would thereby be utilized effectively throughout the year. The program was developed on a step-by-step basis, commencing with the establishment of 1 maintenance unit consisting of 1 foreman and 12 operators. The maintenance unit at the first location had a rather well-balanced work load on 110 miles of roadway consisting of 20 miles of Interstate, 30 miles of hot top, 30 miles of 2-lane concrete pavement on the primary system, and 30 miles of low-type asphaltic surface on the secondary system.

Following the establishment of the original subdistrict, 3 other areas were changed from patrol sections to subdistrict operations. They were headed by a foreman but varied somewhat in size, depending on climatic and traffic conditions, from 70 to the original 110-mile unit. All equipment units remained the same, except the trucks and mowers. In the extreme western part of the state, units have 2 trucks and 2 mowers, while in the Kansas City and Wichita areas several units have 5 trucks and mowers each. The increased work load is not brought about by repair so much as by the increased traffic services such as litter removal, flagging operations, and difficulty in storm coverage.

The final complement of equipment was set as follows:

Equipment	No.
½-ton pickup	1
Medium-duty motor grader	1
Light-duty motor grader	1
Distributor	1
5- to 8-ton roller	1
¾-cu yd loader	1
5-ton capacity truck	4
Mower with 6-, 7½-, or 10-ft cutting capacity	4

Paper sponsored by Department of Maintenance and presented at the 49th Annual Meeting.

In addition there were small motor-driven units such as Gravely mowers and roto-tillers. Total cost for the average maintenance unit was established at about $75,000.

A 5-year program was initiated to unify and regroup all areas throughout the state. This program is now complete. The complement of men and equipment mentioned before was average. In the extreme western section of Kansas the complement was somewhat less, while in the eastern section the complement was larger, due primarily to higher traffic volumes and more populous areas.

Many factors were studied while establishing the final maintenance unit and its equipment complement. One factor of prime importance was to determine the annual work load by first estimating the number of man-hours and equipment unit-hours required to keep a roadway clear during a major Kansas snowstorm, considering the storm's individual characteristics that varied from the extreme western portion of the state to the eastern portion.

Second, an estimate of man-hours and equipment unit-hours for the repair and maintenance of all bridges, roadways, and rights-of-way was required without including backlog or addition and betterment work.

Another important area considered throughout the program was eliminating hand labor whenever possible. Because the desired crew size was fixed by storm coverage need, the goal was to use every man, except the flagmen, as operators. The following are some typical examples:

1. Surface Work. A rigid schedule is set for a portion of each type of surface in each subdistrict to place blade-laid surface patches, to be followed by rolling, fog sealing, and resurfacing annually.
2. Signing and guardrail installations. The boom truck was equipped with power augers, tampers, and hydraulic wrenches.
3. Cleaning bridges and yards. Each division was equipped with pickup-power brooms with road speeds up to 50 mph.
4. Right-of-Way. The bituminous distributor in each subdistrict was equipped with spraying units for all unwanted vegetation previously cut by hand. Landscaping is maintained by roto-tillers and trimming with mechanical pruners on the boom trucks.

Considerable funds are saved through the combined efforts of the foreman and supervisor utilizing every possible labor-saving device.

The equipment was studied in order of importance, using quantity-quality, productivity, and traffic exposure factors for setting priorities. The study was made in the following order.

Trucks

Because the truck dominated all other units in number and was utilized throughout the year, it was chosen first. Our truck fleet consisted of many sizes, types, and ages that varied from new to 15 years old.

Cost—A comprehensive study was made of all units, and they were classified by size, type, kind, and age. We were fortunate in having current total cost records for light-, medium-, and heavy-duty trucks. The 140 light-duty trucks had a total operating cost of $0.072 per mile; 327 medium-duty trucks, $0.057 per mile; and 148 heavy-duty trucks, $0.080 per mile. (Costs are available for all equipment as well as trucks.) The study showed very conclusively that the most economical unit was a medium-duty truck with a 5-ton capacity, operating 5 to 7 years and approximately 140,000 miles. Next, a study was initiated to determine what truck parts were repaired most frequently. This included items such as parts of the body with chloride corrosion damage, body hoists, motors, and transmissions. This study enabled us to determine preferred equipment features such as type of transmission and tire wear.

Body—We were reasonably sure that a truck could operate another 20,000 to 25,000 miles if the body were protected from corrosion. The Research Department was asked to run exhaustive tests on all types of materials. Trucks from various locations throughout the state were chosen, and portions of all body parts were treated. An obvious need for periodic cleaning was the only conclusion reached from the study. This conclusion served a real purpose in that we were able to program for adequate cleaning equipment in each subdistrict.

Central Hydraulic System—Since the truck and all its auxiliary equipment were standardized, it became apparent that a central hydraulic system not only was practical but could prove considerably less expensive if adopted throughout the fleet. The study showed the cost of installation alone would justify its use. We are now adapting other equipment to this system such as hydraulic paving breakers, drills, and augers.

Towed Units

Next, an accident study was conducted on units towed on the roadway, such as pull brooms, distributors, blades, and rollers. From a 5-year record of all accidents covering Kansas State Highway Commission equipment, we found that pull-type equipment was involved in more than 50 percent of the total accidents. Today, virtually all pull-type units have been eliminated and replaced with self-propelled units. The forward and backward movement is required of equipment such as motor graders and rollers. Our study of surface work showed that virtually all accidents occurred during turning movements.

Mowers

Mowers were given the third order of importance with emphasis on quantity-quality standards. Here again, we were fortunate in having some excellent cost data available that had been accumulated throughout the years. They could be used for determining the least expensive mowers. However, no cost records were available for determining production. A further study covering production, or required mowing capacity, was conducted at each subdistrict. The study showed each unit's assignment averaged about 1,000 acres and required mowing 3 to 5 times each season, depending on climatic conditions. Also, it was discovered that the most economical combinations were one 6-ft bar, two 7-ft rotaries, and one 10-ft unit, either a rotary or a flail-type and with a road speed of 40 to 50 mph. The large unit with the road speed of 40 to 50 mph is self-supporting; therefore, it is used to mow shoulders and medians while the other three accomplish cleanup and complete right-of-way mowing. The latter, however, require the use of a nurse truck for transportation, fuel, and parts.

Snow and Ice-Control Equipment

Because each truck was designed, in part, to have a carrying capacity to cover a maximum section of 25 miles hourly during storms, auxiliary equipment was designed to fit the trucks.

Spreaders—By standardization of a central hydraulic system on each truck, all spreader hookups were made identical. A rather simple study showed the original installation expenditure was nearly 25 percent of the original cost and could be almost entirely eliminated.

Snow Plows—All trucks per section are equipped with identical front-mounted, trip-reversible, high-speed plows traveling on dollies. A rather exhaustive study over a 3-year period showed that by using dollies and carbon-tipped blades of identical sizes and types our efficiency almost doubled during a storm period.

Automatic Transmissions—The study showed that by changing to automatic transmissions and eliminating blade and shoe changing we operated with one less man per truck for each shift and with greater efficiency. Then, too, a lesser degree of skill was required for operators, making the training program more efficient by concentrating on productive items.

Surface Maintenance Equipment

Distributor—Considering the elimination of most hand tools, such as shovels, rakes, and towed equipment, and the necessity for a machine-tooled repair, Wilbur Heer, maintenance equipment engineer, designed a 3-section take-off distributor with a capacity for heating small quantities of asphalt needed for small repairs. It was a 600-

gal unit mounted on a 1-ton truck, with fast, maneuverable capabilities. Today, several companies are manufacturing this type of truck-mounted distributor. This particular unit became the key to the development of total mechanization for all surface work. The unit is used not only for bituminous pre-mix production, but for fog coating, linseed oil treatment of bridge decks, crack sealing, and spraying of diesel fuel on vegetation around guardrails, signs, and fence rows. It is a very versatile tool.

Signing—Another project undertaken, under somewhat different circumstances, was the traffic protection of personnel at work sites. Although all procedures complied with the manual, various sign sizes and mounts were developed and used at designated locations. We adopted, for Interstate work, an 8- by 8-ft diamond sign that has 5 flashing lights, is generated by a 5-hp motor, and is mounted on a boat trailer. This sign is placed and maintained at a standard required distance from all work operations. Since using this method, we have never experienced an accident.

OTHER RESEARCH

Cost Records

Kansas, fortunately, has a very fine highway research department with very capable engineers. When assigned a project, this department always follows through, serving the factual data necessary for long-range planning. We have, through the years, utilized much of the data accumulated; but, there were instances in which the data proved of no value and the procedure was eliminated entirely. For example, one study showed that cost accounting by route, county, and type was not being used. We believe cost accounting on all equipment can just as effectively, if not more so, be accomplished by obtaining cost records on sample equipment such as trucks and motor graders within each district. Most would agree that such a procedure will produce good results and that the money saved can effectively be utilized for mechanic or serviceman positions.

Spraying

As mentioned before, Kansas is using a small self-propelled distributor for spraying all unwanted vegetation growth. Our study showed that, by using this unit for a dual purpose, vegetation growth around guardrails and signs could be controlled very effectively at a fraction of the previous cost for hand spraying and cutting.

Crack Pouring

Kansas made a study of all types of materials and procedures for surface crack pouring. The procedure adopted utilized the distributor in the crack-pouring operation. All cracks are filled from the bottom up with a cationic emulsion. This procedure has been in effect about 5 years and has proven very effective, at a fraction of the previous cost.

Shops

About 4 years ago, all shops were equipped with electronic scope analyzers, and a rigid schedule was set for all equipment to be brought to the shops for complete tune-ups or overhauls. The schedule was set at 12,000 miles or 600 hours depending on the method of measuring operating time. Not only has the downtime been cut by 50 percent, but also the operational time of a truck has been increased by 1 year, with a resulting increase in mileage of 25,000 miles.

Safety Lighting Devices

Very elaborate, but standard, safety lighting features were adopted; and all trucks, motor graders, and distributors were equipped with these devices. Accident records for the past 5 years show the overall cost of repairs caused by accidents is decreasing about 10 percent annually or 40 percent less in 1968 than in 1963 even though the exposure factor has increased in this same time period. However, it is difficult to substantiate that the safety lighting features were the prime factor in the repair cost reduction even though they have certainly helped.

WORK CODE CATEGORIES

I. Mainline Roadway Surface and Base

A. Rigid Pavement (Concrete)

111	Surface Patching or Repair	Cu. Yds.
112	Crack or Joint Sealing	Gals.
113	Mudjacking	Cu. Yds.
114	Other	None

B. Flexible Pavement (Hot Mix Bituminous)

121	Mixing Material (Hot Mix)	Cu. Yds.
122	Surface Patching or Repair	Cu. Yds.
123	Surface Sealing	Gals.
124	Crack Sealing	Gals.
125	Other	None

C. Other Pavements

131	Mixing Material (Pre-Mix)	Cu. Yds.
132	Surface Patching or Repair	Cu. Yds.
133	Surface Sealing	Gals.
134	Crack Sealing	Gals.
135	Other	None

II. Shoulders, Side Approaches, and Turnouts:

201	Installation or Repair	Cu. Yds.
202	Sealing	Gals.
203	Reseeding or resodding	Acres
204	Chemical Application (Calcium Chloride)	Tons
205	Blading and Rolling	Miles
206	Other	None

III. Roadside and Drainage:

301	Mowing	Acres
302	Slope and Ditch Repair	Each
303	Reseeding or Resodding	Acres
304	Culvert or Pipe Maintenance	Each
305	Fencing Repair (Right of Way)	Each
306	Litter and Trash Pickup	Each
307	Other	None

IV. Bridges:

401	Painting	Gals.
402	Handrail Repair	Lin. Ft.
403	Deck Repair	Sq. Yds.
404	Abutment or Pier Repair	Each
405	Other	None

V. Traffic Control and Service:

501	Guard Fence Installation, Repair, or Removal	Lin. Ft.
502	Edgeline Painting	Miles
503	Centerline Painting	Miles
504	Traffic Sign or Marker Installation, Repair, or Removal	Each
505	Safety Rest Area and Weight Station Maintenance	Each
506	Sign Manufacturing	Sq. Ft.
507	Other	None

VI. Snow and Ice Control:

601	Snow or Ice Removal	2 Lane-Miles
602	Abrasive Application	Cu. Yds.
603	Chemical Application	Tons
604	Snow Fence Installation or Removal	Rolls
605	Other	None

VII. Capital Improvements (Building and Yards):

711	Painting	Gals.
712	Structure Repair	None
713	Electrical or Mechanical System Repair	None
714	Landscaping	None
715	Janitorial Work	None
716	Driveway Repair	Cu. Yds.
717	Yard Maintenance	None
718	Other	None

VIII. Subsidiary Charges

801	Travel Time	None
802	Weather Delays	None
803	Equipment Repairs	None
804	Equipment Storage	None
805	Leave, (All Types)	None
806	Other	None

EQUIPMENT UNITS

Trucks:	
* Trucks, ½ ton and ¾ ton	2
* Trucks, 1 ton and 6 passenger	3
Light Duty (Dump and Flatbed)	4
Medium Duty (Dump and Flatbed)	5
Heavy Duty (Dump and Flatbed)	6
Tractor (Single Axle)	6
Tractor (Tandem Axle)	10
* All Body Types	
Trailers:	
Tilt-top	4
Lo-Boy Semi	6
Transport (Asphalt and Water)	7
Spreaders:	
Tail-Gate	1
Hopper	2
Motor Graders:	
Light Duty	7
Medium Duty	12
Heavy Duty	14
Snow Plows, All Types	1
Tractors:	
Wheel (All sizes)	4
Crawler with Dozer (All sizes)	17
Loaders:	
Wheel (¾ yard and less)	7
Wheel (1 yard and more)	12
Crawler	17
Distributor, Truck Mounted	6
Roller, Self-propelled (Flat and Pneumatic)	6
Mowers, Power:	
Tractor type (6′)	2
Tractor type (7.5′)	4
Tractor type (10′)	8
Compressor, Air	6
Sweeper, Self-propelled	10
Mudjack	6
Saw, Concrete	1
Powershovel, Truck Mounted and Crawler	35
Hot Mix Plant	30
Center Stripers:	
Medium	12
Large	16
Derrick, Hydraulic Truck Mounted	12

Figure 1. Work codes used in reports.

WEEKLY WORK ACCOMPLISHMENT REPORT

TOTAL UNITS ASSIGNED

Men: 600 (120) SUB-DISTRICT NO. 322

Equipment: 4280 (856) WEEK ENDING 5-10, 1969

DATE	WORK CODE	WORK UNITS PERFORMED	MAN-HOURS USED REGULAR	MAN-HOURS USED OVERTIME	MAN-HOURS USED TOTAL	EQUIPMENT UNIT-HOURS USED
Sunday 5-4						
Monday 5-5	131	60	14		14	123
	132	60	52		52	238
	301	9	4		4	16
	504	1	21		21	28
	801		13		13	31
	804					420
	805		16		16	
Tuesday 5-6	122	12	18		18	24
	131	90	14		14	119
	132	156	56		56	253
	307	17	7		7	32
	801		17		17	37
	804					391
	805		8		8	
Wednesday 5-7	301	10	14		14	32
	307		73		73	273
	801		15		15	30
	803		6		6	86
	804					435
	805		12		12	
Thursday 5-8	132	18	56		56	222
	301	41	14		14	56
	307		14		14	119
	504	1	14		14	28
	801		14		14	33
	804					398
	805		8		8	
Friday 5-9	131	60	14		14	119
	132	15	35		35	133
	205	12	28		28	126
	301	40	14	2	16	72
	801		13		13	54
	803					56
	804					304
	805		16		16	
Saturday 5-10						
		TOTALS	600	2	602	4,288

S. H. C Form No. 339

Figure 2. Weekly report.

DISTRIBUTION MAINTENANCE HEADQUARTERS — WORK ACCOMPLISHMENT REPORT
DIVISION — FOR FISCAL YEAR ENDING JANUARY 31, 1970
DISTRICT — SUB-DISTRICT NO.3-4-3

WORK CODE	DESC.	UNIT	WORK UNITS YEAR ACC	WORK UNITS SUB DIST AVE	MAN HOURS YEAR ACC	%	MAN HOURS SUB DIST AVE	%	WORK UNIT PER MAN HOUR YEAR	WORK UNIT PER MAN HOUR SUB DIST AVE	EQUIPMENT UNIT HOURS YEAR ACC	%	EQUIPMENT UNIT HOURS SUB DIST AVE	%	WORK UNIT PER EQUIP UNIT HOURS YEAR	WORK UNIT PER EQUIP UNIT HOURS SUB DIST AVE
121	MIXING BIT	YDS	127	429	64	0	160	1	1.9	2.6	336	0	1229	1	[illegible]	[illegible]
122	SURF PATCH BIT	YDS	145	517	340	2	358	3	0.4	1.4	1672	1	2559	2	0.	[illegible]
123	SURF SEAL BIT	GAL	0	2969	0	0	76	1	0.0	39.3	56	0	336	0	0.	[illegible]
125	OTHER	NONE	0	0	8	0	104	1	0.0	0.0	40	0	621	0	0.	0.0
131	PRE MIX	YDS	6966	3782	712	4	445	3	9.7	8.5	8736	5	4400	3	0.7	[illegible]
132	SURF PATCH	YDS	10851	3102	3714	19	1886	15	2.9	1.6	31076	16	13757	10	0.3	0.2
133	SURF SEAL	GAL	50133	15506	1672	8	522	4	29.9	29.7	13164	7	3313	2	3.8	4.6
134	CR SEAL	GAL	2065	1878	441	2	215	2	4.6	8.7	1512	1	1051	1	1.3	1.7
135	OTHER	NONE	0	0	684	3	403	3	0.0	0.0	6156	3	2647	2	0.0	0.0
201	INST OR REP	YDS	165	445	152	1	262	2	1.0	1.7	520	0	2140	2	0.3	0.2
205	BLADING ROLLING	MILE	52	7	16	0	9	0	3.2	0.8	112	0	60	0	0.4	0.1
206	OTHER	NONE	0	0	12	0	69	1	0.0	0.0	80	0	500	0	0.0	0.0
301	MOWING	ACRE	5818	3208	3412	17	1788	14	1.7	1.7	15262	8	9202	7	0.3	0.3
302	SLOPE DITCH REP	EACH	14	29	230	1	399	3	0.0	0.0	2200	1	3221	2	0.0	0.0
304	CUL PIPE MAINT	EACH	4	3	68	0	66	1	0.0	0.0	184	0	289	0	0.	0.0
305	FENCE REP (R/W)	EACH	7	3	16	0	69	1	0.4	0.0	64	0	232	0	0.1	0.0
306	TRASH PICKUP	EACH	7	18	112	1	226	2	0.0	0.0	400	0	709	1	0.0	0.0
307	OTHER	NONE	0	0	356	2	461	4	0.0	0.0	1840	1	1806	1	0.0	0.0
401	PAINTING BR	GAL	273	15	128	1	12	0	2.1	1.3	184	0	32	0	1.4	0.4
405	OTHER	NONE	0	0	192	1	120	1	0.0	0.0	1072	1	504	0	0.0	0.0
504	TR. MARKER-SIGN	EACH	237	52	662	3	701	5	0.3	0.0	2190	1	2307	2	0.1	0.0
505	S.R.A.,WT.STA.	EACH	99	56	1194	6	496	4	0.0	0.1	5082	3	1790	1	0.0	0.0
507	OTHER	NONE	0	0	489	2	110	1	0.0	0.0	2180	1	438	0	0.	0.0
601	SNOW ICE REMOVAL	MILE	2285	1567	1220	6	718	6	1.8	2.1	6425	3	4158	3	0.3	0.3
602	ABRASIVE APPL	YD	10	59	4	0	48	0	2.5	1.2	40	0	276	0	0.2	0.2
603	CHEMICAL APPL	TON	261	179	226	1	160	1	1.1	1.1	1881	1	933	1	0.1	0.1
604	SNOW FENCE	ROLL	90	103	112	1	117	1	0.8	0.8	312	0	389	0	0.2	0.2
605	OTHER	NONE	0	0	557	3	268	2	0.0	0.0	2456	1	1179	1	0.	0.0
711	PAINTING BLD,YDS	GAL	2	3	24	0	27	0	0.0	0.0	96	0	42	0	0.	0.0
712	STRUCTURE REP	NONE	0	0	16	0	5	0	0.0	0.0	0	0	4	0	0.0	0.0
715	JANITORAL WORK	NONE	0	0	124	1	86	1	0.0	0.0	0	0	138	0	0.	0.
716	DRIVEWAY REP	YDS	105	33	80	0	16	0	1.3	2.0	320	0	82	0	0.3	0.
717	YARD MAINT	NONE	0	0	160	1	151	1	0.0	0.0	776	0	794	1	0.	0.
718	OTHER	NONE	0	0	40	0	55	0	0.0	0.0	152	0	288	0	0.0	0.
801	TRAVEL TIME	NONE	0	0	32	0	290	2	0.0	0.0	184	0	855	1	0.0	0.
802	WEATHER DELAY	NONE	0	0	12	0	20	0	0.0	0.0	0	0	689	1	0.	0.
803	EQUIP REP	NONE	0	0	192	1	163	1	0.0	0.0	6248	3	6769	5	0.	0.
804	EQUIP STORAGE	NONE	0	0	48	0	26	0	0.0	0.0	76418	40	60920	45	[illegible]	[illegible]
805	LEAVE	NONE	0	0	2300	12	1216	10	0.0	0.0	1012	1	692	1	0.	[illegible]
806	OTHER	NONE	0	0	100	1	145	1	0.0	0.0	544	0	3116	2	[illegible]	[illegible]
	TOTALS TO JANUARY 31				19921		12778				191062		135779			

Figure 3. Monthly feedback report.

Reporting

As each maintenance unit was organized, equipped, and manned to the designed strength, a quantity production reporting procedure was initiated. The program calls for a daily report from each subdistrict foreman showing the man-hours, equipment unit-hours, and work units accomplished. These are forwarded weekly to the headquarters maintenance office, checked, and given to the computer section for keypunching. The final feedback report from the computer section shows, by coded work item, the work units, man-hours, and equipment unit-hours plus the work units per man-hour and equipment unit-hour. The codes and reports are shown in Figures 1, 2, and 3. All units are self-explanatory except the "Equipment Unit" (Fig. 1), which is based on the purchase price; for example, a $5,000 truck would carry 5 equipment units, and a $12,000 motor grader, 12 units. The feedback report also shows the relative efficiency of the subdistrict, district, and division within the state. Currently, the work accomplishment program is in operation throughout the state and is used several ways in addition to reporting work performed.

Different types, kinds, and sizes of equipment are grouped to measure factors such as the relative downtime and overall productivity with the hope of improving specification writing, the relative impact on-the-job training has to downtime, repairs, and productivity. It is believed the program will contribute considerably toward the rating and promotional factors of personnel on the supervisory level. Its most important contribution, however, if properly used, will be in budgeting operations.

CONCLUSIONS

Kansas has recognized a substantial gain in quantity-quality production and in safety as a result of continually applied research. However, we believe all programs in these areas should be routine, and similar ones should continue indefinitely, alerting or bringing to the attention of all employees more efficient methods and procedures.

Total Cost Purchasing Applied to State Heavy Equipment Procurement

IRA F. DOOM, Virginia Highway Research Council

This paper describes a study initiated in 1965 on how to purchase dozers, loaders, and graders at the least overall cost to the Virginia Department of Highways, and gives the results of the department's implementation of the study recommendations in 1967. The purposes of the research were (a) to determine the objectives of the department's heavy equipment buying program and to evaluate the effectiveness of existing equipment purchasing procedures in achieving these objectives; and (b) to determine the need for improvement and to state where these needs exist and how they might be fulfilled. The department's equipment procurement objectives were to satisfy equipment needs at the least cost consistent with desired performance; and the method used to achieve this objective was to buy equipment that met the specifications of the equipment engineer at the lowest bid price and replace it after a set number of years. The research indicated that the true lowest cost is not necessarily reflected in the lowest bid price but rather in the least overall cost per equipment operating hour. The method to ensure lowest cost equipment procurement is to evaluate suppliers on the basis of alternate bids, that is, to permit them to bid on initial price only and project this bid to a total cost per hour figure based on the department's past experience, and to allow them to guarantee total hourly costs if they chose to do so.

Results of implementation of study recommendations were that, for motor graders, the initial price method proved to be substantially cheaper in total cost per hour terms than the guaranteed cost per hour method. The lowest guaranteed total cost bid submitted to the department was $0.30 per hour greater than the projected costs of the initial price bid. Based on 12,700 hours' usage of 15 graders (the number purchased), Virginia saved over $50,000 by not awarding the bid on the basis of the lowest guaranteed total cost. Moreover, had interest not been used in the purchase evaluation, the guaranteed total cost method would have been considered cheaper and would have resulted in a fictitiously low statement of costs and an improper management decision.

•THIS PAPER DESCRIBES A STUDY initiated in 1965 on how to purchase dozers, loaders, and graders at the least overall cost to the Virginia Department of Highways and gives the results of the department's implementation of the study recommendations in 1967.

Data analysis and detailed investigation in the study were restricted to motor graders because of the length of time involved in obtaining intimate knowledge and cost data for individual pieces of equipment. Some specific conclusions relating to specificatiions and costs were therefore restricted to motor graders, although the general principles of total cost evaluation apply to dozers and loaders as well.

Paper sponsored by Committee on Maintenance Equipment and presented at the 49th Annual Meeting.

The purposes of the study were (a) to determine the objectives of the department's heavy equipment buying program and to evaluate the effectiveness of existing equipment buying practices in achieving these objectives, and (b) if the evaluation indicated needs for improvement, to state where these needs existed and how they might be fulfilled.

The department's equipment buying objectives were to satisfy its needs at the least cost consistent with desired performance, and the method used in the pursuit of this aim was to buy equipment that met the specifications of the equipment engineer at the lowest bid price and replace it after a set number of years (10 for graders). Grader specifications of the equipment engineer were compared with those suggested by the manufacturers. It was generally found that the manufacturers desired many additions that would eliminate or hinder their competitors and result in higher bid prices to the department without any appreciable offsetting benefits.

In conversations with suppliers concerning what factors should be included in computing the cost per hour of heavy equipment and in what way (if any) the performance of one brand of grader is superior to that of another, they cited the following factors as relevant in equipment costs per hour: initial price; resale value; parts cost; labor costs; costs of capital; obsolescence, insurance, and convenience; service and parts distribution capabilities and policies of the supplier; total hours used; and maintenance practices of the user. Although all these costs are relevant in evaluating overall hourly equipment costs, only initial price, costs of capital (interest), repair parts (cost and delivery time), and the resale value depend on the specific brand of equipment purchased. No assertions or evidence was offered by any of the suppliers that their grader was superior in performing those tasks for which the department utilizes graders, specifically, ditch pulling, shoulder work, snow removal, and general road maintenance.

The cost per hour of equipment (and perhaps more importantly the amount of work done) depends a great deal on the availability of parts. Although there were provisions for emergency requisition of parts, discussions with field people of all capacities revealed considerable dissatisfaction with this availability. Recommendations given for solving the repair parts delay problem were as follows:

1. Stipulating as a condition of bid on new equipment that manufacturers or suppliers or both must guarantee by performance bond or cash reserve for a 10-year period (inasmuch as parts would be purchased from them in the future on a direct or indirect basis) that repair parts for this equipment would be supplied to the state within a specified number of business days (five was suggested) from the time of the dealer's or manufacturer's receipt of order from the state except in cases of war, acts of God, strikes, and national emergency;
2. Establishing provisions for a penalty on a per day basis when parts delivery is delayed beyond 5 working days;
3. Securing of repair parts bids by yearly needs;
4. Direct ordering of these parts by the department's district offices from the successful dealers; and
5. Utilizing, if necessary (in conditions of national emergency or when felt desirable), district shop space to stock repair parts in a manner that would prevent equipment downtime.

Under the former method of purchasing, once the department had acquired equipment it became a captive repair parts market for the equipment manufacturers (because there are no alternative parts manufacturers), which resulted in payment for repair parts at higher than manufacturer list prices and delay in delivery times.

Besides parts delivery time, apparently the only way to determine the least cost method of purchase of graders, loaders, and dozers is to offer bidding on an alternate basis. For graders such a bid would allow these choices for the supplier: (a) bid on an initial price basis with the remaining costs being projected into cost per hour terms by the state on the basis of past cost records, or (b) guarantee a total cost per hour in terms of initial price, interest, guaranteed parts cost, and a minimum resale value (Fig. 1). It is noted that total guaranteed costs were expressed in 5-year or 6,350-hour terms for heavy-duty graders with tandem drive. This was because (a) usage patterns for these graders averaged 1,270 hours per year over the last 5-year period prior to

Prospective suppliers can bid either on lots, on total cost basis or initial price only. Bids made on initial costs will be projected into total costs as described below. Total cost bids are for 6350 hours or 5 years, whichever comes first.

	Total Guaranteed Cost			Projected Initial Price Bid	
	Initial Price	-------------		Initial Price	----------------
+	Interest Compounded at 4% (216 per 1000)	-------------	+	Interest Compounded at 4% Per Annum (480 per 1000)	----------------
+	Guaranteed Maximum Parts Costs (not to exceed Manufacturer's Published Price Lists	-------------	+	Estimated Parts Cost (28 cents an hour for 12,700 Hours)	$3556.00
=	Total Initial Price	-------------	=	Total Initial Costs	----------------
—	Guaranteed Repurchase Price at 5 Years	-------------	—	Estimated Resale Value at End of 10 Years (9% of Initial Price)	----------------
=	Net Bid Price	-------------	=	Estimated Net Total Hours	----------------
—	Estimated Hours Used, 5 Year Period	6,350	—	Estimated Hours Used Over 10 Years	12,700
=	Net Total Cost Bid Price Per Hour	-------------	=	Estimated Net Costs Per Hour	

Figure 1. Proposed method of awarding bid for heavy-duty graders with tandem drive.

release of recommendations with relatively small variations (100 hours) in average yearly activity, and (b) suppliers stated that five is the maximum number of years for which a bid bond could be obtained. If bid bonds could be obtained for more than 5 years, then the researchers would have recommended that suppliers be allowed to guarantee total costs on a 5-, 6-, 7-, 8-, 9-, or 10-year basis rather than confining the number of years to five. A maximum of 10 years or 12,700 hours would have been insisted on because the hours used by the department are considerably reduced beyond this grader age. It was recommended that, if bonding conditions changed, a 5- to 10-year bidding period be used at the supplier's option.

Results of the study were the general implementation of the recommendations made. Stipulations were made providing assurances to the department that it would receive adequate delivery of repair parts and certain provisions were made regarding direct ordering of parts including securing them on a yearly needs basis. In the fall of 1967 bidding was permitted on the alternative basis recommended in the study (projected total hourly costs of an initial price bid as compared with total guaranteed hourly costs). The bidding procedures incorporated in the specification conformed to those suggested in the study and were used in purchasing 15 motor graders. The lowest guaranteed total cost bid submitted to Virginia was $0.30 per hour greater than the projected costs of the initial price bid. Based on 12,700 hours' usage per motor grader, Virginia saved over $50,000 by not awarding the bid on the basis of the lowest guaranteed total cost. More important, however, if interest were not used in the purchase evaluation, the guaranteed total cost method would have been considered cheaper and would have resulted in a fictitiously low statement of costs and an improper management decision. Furthermore, this mistake probably would have been repeated several times and would have cost the department hundreds of thousands of dollars as well as creating the illusion of substantial dollar savings.

It is suggested that total cost purchasing does not necessarily require the awarding of the bid to the supplier that offers the lowest guaranteed total 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 versus lowest guaranteed total costs). The principle of total cost bidding is however viewed as sound provided that the purchaser (a) knows his costs of operation under his current purchasing procedures, (b) includes interest in his calculations, (c) compares results of alternative methods of purchase, and (d) does not accept "total cost" formulas until their implications have been thoroughly evaluated. In addition, guaranteed total costs may be more favorable to a purchaser of dozers and loaders because of greater similarity in initial prices of different brands of this equipment than in those of different brands of motor graders.

PRELIMINARY RESEARCH

As a result of the department's adoption of performance purchasing of tires and the contention of some suppliers that initial price was only a part of total equipment acquisition costs, considerable attention was directed at the outset of the study toward the enumeration and definition of the costs of equipment acquisition. The other topic immediately explored was the contention of some suppliers that their equipment was superior in performance. In brief, preliminary research was restricted to costs and performance.

At this point the researchers realized that many kinds of costs would be involved and discussions would have to be held with all interested suppliers. It was therefore considered prudent to confine data collection and supplier contacts to motor graders so that one piece of equipment would be researched in detail rather than all kinds of heavy equipment being examined cursorily. It was felt, however, that certain general purchasing principles applying to dozers and loaders as well as graders would be established.

After several meetings with the various suppliers and a preliminary data search, the researchers reached the following conclusions:

1. Initial price, repair parts costs and delivery time, and resale value are all elements that should be taken into account in equipment acquisition;
2. Differences in initial price could be viewed either in terms of funds foregone for other investment purposes or in terms of accrued interest that could be earned on the difference of dollars between the low bid and other bids; and
3. Under present utilization practices, graders used by the department become obsolete after 10 years but not before.

The significance of discrepancies in resale values is given in Table 1. Resale values

TABLE 1
RANGE OF RESALE VALUES

Year	A	Number in Sample	B	Number in Sample	C	Number in Sample	D	Number in Sample	E	Number in Sample
Good Condition Motor Graders in 1964										
1952-54	2,300-2,500	3	4,600-7,500	10	2,450	1	NA	NA	NA	0
1955-57	2,500-3,100	3	5,700-10,000	23	1,350-1,800	3	2,900-3,300	2	NA	0
1958-60	3,700	1	8,500-12,100	6	NA	0	5,000	1	5,000	1
1961-63	NA	0	12,100-16,750	8	NA	0	NA	0	NA	0
Fair Condition Motor Graders in 1964										
1952-54	1,250-1,550	5	3,200-4,100	6	1,600	1	1,500	1	NA	
1955-57	1,000-2,000	6	4,100-7,000	5	1,000	1	1,600-1,650	2	NA	
1959-60	2,100-2,700	3	7,500-10,500	2	1,750	1	NA	0	NA	
1961-63	NA	0	NA	0	NA	0	NA	0	NA	
Good Condition Motor Graders in 1965										
1953-55	3,900	1	4,300-8,600	8	2,700-2,900	2	NA	0	NA	0
1956-58	3,200	1	7,500-9,000	13	4,100-4,700	4	NA	0	1,800	1
1959-61	4,750	1	9,400-13,000	5	NA	0	NA	0	NA	0
1962-64	NA	0	12,200-14,750	5	NA	0	NA	0	NA	0
Fair Condition Motor Graders in 1965										
1953-55	1,000-1,900	3	2,900-3,850	5	NA	0	NA		NA	0
1956-58	1,900-2,500	2	4,600-6,750	10	1,800-2,900	2	NA		750-900	2
1959-61	2,100-2,800	3	NA	0	NA	0	NA		3,000	1
1962-64	NA	0	NA	0	NA	0	NA		NA	0

Source: 1964—Bluebook of Current Market Prices of Heavy and Used Construction Equipment, Forke Brothers, Lincoln, Neb., 1964 Entire Year Edition, pp.91-116, for 1964 data, and 1965 Entire Year Edition, pp. 93-118, for 1965 data.

Note: Letters A–E indicate individual brands of graders.

TABLE 2

AVERAGE HOURS USED PER HEAVY-DUTY GRADER BOUGHT BETWEEN 1947 AND 1956

Years Old	Number in Sample	Total Hours Used	Average Hours Used
8	22	16,093	1,288
9	32	33,865	1,058
10	37	39,642	1,071
11	38	29,913	787
12	33	24,283	736
13	26	14,063	541

Source: Cost records reported by the Electronic Data Processing Division, Virginia Department of Highways.

of various brands but comparable model graders are substantially different—in some cases by as much as $5,000. Although it was felt that higher resale values should be allowed to offset higher initial bid prices, it should be recognized that there is a financial significance to a delay period before resale prices are received. If, for example, the state were to purchase one grader at $20,000 and receive $10,000 at the end of 10 years and another grader at $10,000 and receive nothing at the end of 10 years, it would initially appear that because the state is making a net payment of $10,000 in both cases the offers were equal. This would not be the case, however; in the case of the first grader, the state would be foregoing the use of $10,000 for a period of 10 years. Looked at another way, the state would be sacrificing $4,800, based on 4 percent compounded interest for 10 years. In other words, in order for the $20,000 to be an equal offer a resale value of $14,800 would have to be offered, assuming foregone funds were valued at 4 percent compounded for 10 years.

Although statistics on the parts costs of different brands of equipment were not readily available, the various suppliers indicated that if parts costs guarantees were asked for they would each quote different maximum parts cost figures. From this information and the subsequent data, it should be clear that initial price is only one of the costs that should be considered in equipment acquisition decisions.

Another principal topic of discussion with the distributors was obsolescence. It was the author's opinion, considering the state's usage requirements, that obsolescence occurs when the hours used per grader value declines sharply. A search of the data indicated that this event occurs at about 10 years (Table 2).

The final subject covered in preliminary research was the possibility of variation in performance among different brands of graders. Some of the distributors stated that their graders were better than others. Every effort was made to determine if there is in fact variation in grader performance for the tasks for which the department employs graders, specifically ditch pulling, shoulder work, snow removal, and general road maintenance. The distributors, after recurrent questioning, admitted that there were no criteria by which their graders were superior for use except lower parts costs, speedier parts delivery, and higher resale values. Because the researchers had already envisioned these criteria being taken into account, performance considerations were abandoned temporarily.

EQUIPMENT SPECIFICATIONS

The researchers visited manufacturing plants and consulted with personnel of some of the companies that produce motor graders. A principal subject of examination was the possibility of the department adding to its specification requirements numerous features that the manufacturers considered beneficial to grader operation. Among those suggested were (a) minimum requirements for the base weight of graders and the weight at the midpoint of their frames; (b) automatic overload relief devices such as bypass valves, torque limiters, hydraulic kick-out valves, or electric sensoring safety switches; (c) 4-wheeled power-boosted hydraulic operating brakes; (d) an accelerator-decelerator foot pedal; (e) a safety tinted windshield; and (f) an audible backup alarm.

No evidence was furnished or discovered that the performance of the tasks for which the department's graders are used would be improved by minimum requirements of base and frame weight or by four-wheeled power-boosted hydraulic operating brakes as opposed to mechanical brakes. These items were not standard on existing models of all brands of graders then being bid to the state. The suppliers of these graders would have to substitute hydraulic for mechanical brakes and add to their frame weight—perhaps through a heavier duty grader with features that the bid hydraulic equipped grader does not have—and so the price competition between suppliers would be reduced

TABLE 3

A COMPARISON OF MONEY SPENT ON MOTOR GRADER SUPPLIES WITH TOTAL MONEY SPENT ON MOTOR GRADER REPAIR PARTS INCLUDING SUPPLIES FROM JULY 1, 1962, TO JUNE 3, 1965

Year Bought	Number in Sample	Total Repair Parts (Including Supplies)	Supplies Only	Supplies as Percent of Total Repair Parts Cost
1958	6	19,496	13,104	67
1959	2	5,301	5,025	95
1960	4	12,247	10,284	84
1961	16	34,008	29,902	88
1962	19	37,396	32,726	88
1963	41	53,657	48,470	90
1964	28	17,263	16,192	94

Source: Cost records of the Equipment Division and requisition sheets of the Purchasing Division, Virginia Department of Highways.

with no offsetting benefits accruing to the state. The same situation is true for an automatic overload relief valve. This is not to say that these features might not be desirable for work in heavy construction, but it appears that the grader requirements of the department for light construction and maintenance are not nearly so severe as for heavy construction and "fine grading."

An accelerator-decelerator foot pedal would probably ease the task of the operator and the safety tinted glass would make him more comfortable by reducing glare. An audible backup alarm seems to be a prudent thing to have; it would reinforce the safety consciousness of operators and possibly prevent backup accidents because of the advance warning to someone behind a grader—either on foot or at the wheel. The U. S. Post Office has installed this device with the result of a considerable reduction in backup accident experience. Although these features would cost the state a little more money, they would be uniform "add-ons" and would not give the supplier of one brand of grader a competitive advantage over the supplier of another. It was, therefore, suggested by the author that the addition of these features in motor grader specifications, provided they did not hinder competition, would be beneficial to the department.

REPAIR PARTS COST AND SUPPLY CONSIDERATIONS

As stated earlier, only initial price, repair parts (costs and delivery time), resale value, and foregone interest costs depend on the specific brand of equipment purchased. Because of this, these are the only costs that must be taken into account when evaluating alternative brands of equipment. In the case of repair parts there are 2 categories: (a) supplies of wearable items—grader blades, scarifier teeth, oil filters, hoses, glass, and tires; and (b) parts—all other items such as rings and valves.

Supplies of wearable items represent the principal expenditures of the two but could not be practically taken into account in cost evaluation. This was because none of the suppliers was willing to guarantee supply costs, contending they were directly dependent on grader usage rather than on grader quality. Efforts were made to derive a method by which the supply portion of parts costs would be guaranteed, but no satisfactory solution was found. The significance of supply costs is given in Table 3. Although most of the data show that more than 80 percent of repair parts costs was accounted for by supplies, it is suggested that the 67 percent shown for 1958 graders is probably more representative. This is because these graders were 4 to 7 years old between 1962 and 1965, or approximately at the midpoint of a 10-year life cycle. In other words, as graders get older the percentage of repair costs that supplies represent becomes smaller. No records of older graders were available, but the researchers estimate that in the tenth year supplies would represent only 33 percent of repair parts and supplies costs but that supplies account for about two-thirds of repair parts cost when the entire life of a grader is considered.

Although admittedly supplies are an important item in grader costs, there seemed to be no possibility of distributors being willing to guarantee maximum supply costs for graders. It was therefore felt that the parts cost (nonwearable items) should be separated on the records of the Electronic Data Processing Division. If this were done, then parts cost might be taken into account in terms of guaranteed bidding.

It was felt that, although the dollar costs of parts were important, perhaps a more significant consideration involving repair parts was the speed of their delivery time. The delays in delivery to the department from time of order were therefore compared with delays encountered by the private construction industry. The basis for comparison was the delay time encountered by the Lynchburg district in its orders for grader parts and the delay time encountered by A. B. Burton Co. of Lynchburg for delivery of parts to the same city. A sample of delay times experienced by the Lynchburg district is given in Table 4. The average number of days between the date of requisition by the Lynchburg district and the date when purchase order was placed by the Division of Purchase and Stores was a little more than 4 days, and the total delay time between the date of requisition and receipt by the Lynchburg district averages slightly more than 12 days, making eight the number of days caused by supplier delay. Total delay for the A. B. Burton Co. averages about 1 day as opposed to 12 days for the Lynchburg district. This 11-day differential would not be unsatisfactory if the parts were being purchased only for inventory purposes; however, conversations with field personnel indicated that such was not the case but rather that the graders were down because of parts delays.

TABLE 4

DELAY TIME OF DIFFERENT ORDERS FOR PARTS IN LYNCHBURG DISTRICT

Requisition	Purchase Order Placed[a]	Parts Delivered to Lynchburg[a]
1	2	7
2	3	5
3	2	7
4	3	6
5	2	7
6	6	11
7	0	3
8	6	10
9	4	12
10	2	28
11	7	9
12	7	17
13	5	19
14	6	20
15	6	28
16	4	6
17	10	14
18	2	14
19	2	10
Total days	79	233
Average days per order	4.15	12.26

Source: Lynchburg district shop clerk.

[a]In days from requisition date from January to June 1966.

Examples of parts delays encountered in the Salem district are given in Table 5. (It should be noted that provisions have been and are available that allow the districts to order parts directly on an emergency basis, which if used would result in elimination of delay between date of requisition and placement of purchase order.)

One method of eliminating the delay problem was to stock all the repair parts for dozers, loaders, and graders that it was anticipated would be needed in the districts. This would have required an analysis of past parts needs and continuous records for prediction purposes. It was suggested that this could be done extensively but that the department would be unnecessarily providing inventory and record-keeping services for some suppliers while other suppliers are already willing to provide these services to the department. In cases where equipment is over 10 years old—if it has not been replaced—parts probably should be stocked in terms of anticipated needs for 30 to 60 days, because parts have to be specially made in many instances for equipment of this age.

TABLE 5

DELAY TIME OF DIFFERENT ORDERS FOR PARTS IN SALEM DISTRICT

Requisition	Purchase Order Placed[a]	Parts Delivered to Salem[a]
1	5	40
2	2	17[b]
3	5	26
4	13	24
5	2	22

[a]In days from requisition date from July to August 1966.
[b]Either none of the order or only part of the order had been delivered as of September 2, 1966, the time of receipt of data.

In order to derive a method by which the department could ensure that it would have adequate parts delivery time, the researches had to analyze and verify the market structure for these parts. The heavy equipment market structure for state business has 2 principal characteristics:

1. The industry is very competitive in the prices of equipment because several brands meet the department's specifications (this is particularly true in the case of motor graders); and

2. Competition for parts business is restricted to distributors of the one manufacturer who supplys the parts for a single brand of equipment.

One result of this situation is that the state gets a very good price on heavy equipment because of volume purchases. This low price is not to be taken for granted as most state and local government purchasing of heavy equipment is done in rather small lots (1 to 10) and the prices are appreciably higher. A lesson might be drawn here that pooling of local government purchase orders offers substantial benefits to these governments.

An unfavorable result of the marketing structure for heavy equipment is the lack of concern on the part of the manufacturer regarding prices and delivery time of parts. In some cases the department had actually paid higher than manufacturer's list price for parts because there are no alternative producers and the manufacturers can charge higher costs to their dealers for parts to be sold to the state. This price abuse had been recognized, and the Division of Purchase and Stores was considering stipulations in bid proposals that the manufacturer awarded the grader, dozer, loader, or other equipment business (directly or indirectly) would be required to sell repair parts to the state equal to or at a fixed percentage below manufacturer's list prices. It was suggested that this consideration be acted upon.

As a result of the analysis of the market structure of heavy equipment, it was suggested that the department specify in its bid proposal that the manufacturer or supplier or both will guarantee repair parts delivery within 5 working days from his dealer's receipt of the department's order or the manufacturer's receipt itself if parts are furnished direct. It was recommended that penalty provisions be made on a per day basis for delays in delivery beyond this time in order to ensure prevention of unnecessary equipment downtime. It was also suggested that a performance bond or cash in escrow be provided for inasmuch as the manufacturer is assured of the state's repair parts business for its equipment.

It was felt that the department should eliminate whatever aspects of its own procedures that contribute to delays of repair parts—namely, the time between requisition date and order date. This delay can be overcome by allowing the district offices to order directly from the parts suppliers. By policy of the Highway Commission, direct orders can be made only in times of emergency; otherwise, competitive bidding is required. Because most repair parts needs are of an emergency nature (or should be if equipment is efficiently utilized except in cases of inventory stocks), extensive use of this provision would eliminate even dealer competition for parts. It was suggested that, if bids for repair parts needs are secured on yearly contracts, all parts would be supplied on a basis that is as competitive as possible while at the same time delays between requisition and order dates would be eliminated.

GRADER COST AND USAGE PATTERNS

The next step in the research was to determine the department's total costs for graders. Factors included in this calculation were initial price, hours used, repair parts costs (delivery time having already been taken care of), foregone interest, and resale value. These costs were for heavy-duty graders with tandem drive. Makes and models of these graders bid to the state in 1965 included Allis-Chalmers M-70, Galion 104, Huber Model 9-D, LeTourneau Westinghouse Model 330-H, and Pettibone-Milliken Model PM 401 A. Caterpillar indicated that if a total cost bid were introduced it would bid on a Cat 120.

Initial price in 1966 was $11,849. Hours used for heavy-duty graders with tandem drive per year was estimated to be 1,269, based on the department's experience from July 1961 to June 30, 1965 (Table 6).

Repair parts costs (excluding supplies) were estimated to be 28 cents per hour used

TABLE 6

AVERAGE HOURS USED FOR HEAVY-DUTY MOTOR GRADERS WITH TANDEM DRIVE BOUGHT FROM 1958 TO 1963

Fiscal Year Ending	Total Hours Used	Number in Sample	Average Hours Used
1962	17,112	12	1,426
1963	34,056	28	1,216
1964	55,122	48	1,148
1965	114,377	89	1,285
Average hours used for all graders (5,075/4)			1,269

Note: Year bought is not included in usage figures because this would only reflect part of a year's usage.

TABLE 7

PARTS COST (EXCLUDING LABOR AND SUPPLIES) OF HEAVY-DUTY GRADERS WITH TANDEM DRIVE FROM 1962 TO 1965

Year Bought	Number in Sample	Total Cost	Total Hours Used	Average Cost Per Hour (cents)
1958	6	6,392	22,800	28.04
1959	2	276	7,994	3.45
1960	4	1,963	14,723	13.33
1961	16	4,106	55,998	7.33
1962	19	4,670	69,427	6.73
1963	41	5,187	111,796	4.64
1964	28	1,071	35,700	3.00

Source: Requisition sheets of the Purchasing Division, Virginia Department of Highways.

Note: One grader, ED No. 14495, was eliminated from data because it was involved in an accident causing heavy damage.

based on the experience of the department between July 1, 1962, and June 30, 1965 (Table 7). The costs of the 1958 graders were deemed the most representative in this table, because the graders were 4 to 7 years old or in the middle of their 10-year life span. The other graders were at a cycle of life—particularly the 1962-1964 ones—when parts costs were the lowest.

Foregone interest at 4 percent compounded for 10 years amounts to 480 per $1,000 or $5,687. The evaluation of interest at this rate was based on the, then appropriate, rate of tax exempt bonds. Resale values at the end of 10 years were estimated to be 8.76 percent of the purchase price in dollars. This estimate was derived from the department's resale experience in 1964 and 1965 given in Table 8.

TABLE 8

AVERAGE RESALE VALUE OF DEPARTMENT-OWNED MOTOR GRADERS AS A PERCENT OF ACQUISITION PRICE

ED Number	Year Grader Bought	Acquisition Price	Resale Price	Resale Price as Percent of Acquisition Price
		1951-1956 Graders in 1964		
5347	1951	10,150	982	9.67
3211	1953	9,549	703	7.36
3214	1953	9,196	703	7.64
3216	1953	9,196	851	9.25
6604	1956	11,171	960	9.59
7624	1956	10,583	1,676	15.84
6889	1955	9,936	700	7.05
4781	1951	10,050	803	7.99
4641	1952	9,104	201	7.21
3238	1953	9,424	953	10.11
All graders		98,359	8,532	8.76
		1952-1957 Graders in 1965		
05453	1952	9,660	485	5.02
6071	1956	11,522	802	6.96
05452	1952	9,660	765	7.92
4893	1952	9,894	915	9.25
6150	1956	10,636	950	8.93
11280	1954	9,985	1,111	11.13
11281	1954	9,525	842	8.84
6466	1954	9,419	842	8.94
03198	1952	9,695	1,250	12.89
All graders		89,996	7,962	8.85

Source: Surplus property records of the Division of Purchase and Stores, Virginia Department of Highways.

Note: Includes all graders over $5,500 acquisition price. Graders included were in fair condition; there was none in good condition.

Based on these data, the net cost per hour that is dependent on the particular brand of grader purchased is $1.58, derived as follows:

Initial price + repair parts + foregone interest = total grader cost
($11,849) ($3,556) ($5,687) ($21,092)

- resale value = net grader cost ÷ hours used for 10 years
($1,038) ($20,054) (12,700)

= net cost per hour
($1.58)

In summary, estimates for pertinent cost and usage data for heavy-duty graders with tandem drives are as follows:

Item	Amount
Initial price	11,849
Hours used at 1,270 per annum for 10 years	12,700
Repair parts and labor at 28 cents per hour for total usage of 12,700 hours	3,556
Foregone interest (1966 prices) based on 4 percent compounded for 10 years	5,687
Resale value of 8.76 percent of $11,849	1,038

TOTAL COST PURCHASING

Because all of the costs dependent on the specific brand of equipment were put into cost per hour terms, it remained to be shown how they could be utilized to improve the effectiveness of grader acquisition. It was suggested that in the purchasing of graders 2 things should be evaluated on a continually current basis: (a) the brands of graders, and (b) the method of purchase.

Acceptable brands of graders could have been determined through materials specifications, but the best method of purchase can be determined only through the issuance of alternate bids supported by adequate cost data. The first alternative would be to allow suppliers to quote on the basis of initial price only and to project grader costs per hour from past experience.

Specifically the technique would work as follows:

1. Each supplier would quote his low bid, say $12,000;
2. Hours used would be assumed to be 12,700, cost for repair parts, $3,556, and foregone interest, $5,760 (4 percent on $12,000 compounded for 10 years);
3. The resale value at the end of 10 years would be estimated at 8.76 percent of $12,000, or $1,051; and
4. Total bid but not guaranteed costs on a $12,000 bid would be $12,000 + 3,556 + 5,760 = $21,316 - 1,200 = $20,116 ÷ 12,700 = $1.58 cost per hour.

If on the other hand the supplier would prefer to guarantee costs, it was felt that he should be allowed to do so on a 5-year or 6,350-hour basis, whichever comes first. If the supplier wanted to bid on a 6 to 10 year basis assuming 1,270 hours annual usage, it was suggested that this should be permitted. Possible bids under this arrangement are given in Table 9.

In the case of guaranteed bidding, bid bonds were recommended to be required for the amount of resale value guaranteed and for a sum of $3,500 per grader to cover parts cost. Indications were that suppliers could not obtain bid bonds for more than 5 years. Guaranteed bidding in practice was therefore restricted to 5 years or 6,350 hours, whichever comes first.

It was noted that in the case of guaranteed bidding the suppliers would want to have the department follow specific grader maintenance practices. It was suggested that these practices be submitted with a guaranteed bid and that if reasonable the department would make every effort to follow them. However, it was recommended to be stated

TABLE 9

POSSIBLE GUARANTEED TOTAL COST BIDS FOR HEAVY-DUTY MOTOR GRADERS WITH TANDEM DRIVE

Cost Elements	Brand A	Brand B	Brand C
Initial bid price	12,000	20,000	11,500
Foregone interest based on 4 percent compounded for number of years bid	2,592	4,320	5,520
Maximum parts cost	1,500	300	3,500
Net total cost bid	16,092	24,620	20,520
Guaranteed minimum repurchase price	2,000	12,000	0
Net bid guaranteed cost	14,092	12,620	20,520
Number of hours or years bid (Basis 1 year = 1,270 hours)			
Years	5	5	10
Hours	6,350	6,350	12,700
Net bid cost per hour	2.22	1.99	1.62

on the bid proposal that continuance or improvement of current equipment maintenance practices would be satisfactory. If not, the department might have awarded a bid expecting substantial savings only to find out that certain guarantees did not apply unless suppliers agreed to the department's performance practices. This seemed reasonable as the department's projected parts cost and resale values were based on past and current maintenance practices.

It was further suggested that in the case of guaranteed parts cost of graders the low costs of one be allowed to compensate for the high costs of another. For example, if a supplier guarantees $1,500 parts cost and on one piece of equipment the costs are $2,000 but on another $1,000, the evaluation of supplier performance would be based on the average not on individual graders.

It was reiterated that this type of bidding should be used for dozers and loaders as well as for graders and on a continuing basis. Procedures for calculation of existing total costs for dozers and loaders were viewed as the same as those for graders.

RESULTS AND REFLECTIONS

Results of the study were the general implementation of the recommendations made. Stipulations were made providing assurances to the Virginia Department of Highways that it would receive adequate delivery of repair parts, and certain provisions were made regarding direct ordering of parts including securing them on a yearly needs basis.

In the fall of 1967 bidding was permitted on the alternative basis recommended in the study (projected total hourly costs of an initial price bid as compared with total guaranteed hourly costs). The bidding procedures incorporated in the specifications conformed to those suggested in the study and were used in purchasing 15 motor graders.

Data given in Tables 10 and 11 indicate that the lowest guaranteed total cost bid submitted to Virginia was $0.30 per hour greater than the projected costs of the initial price bid. Based on 12,700 hours' usage per motor grader, Virginia saved over $50,000 by not awarding the bid on the basis of the lowest guaranteed total costs.

More important, however, as revealed by data given in Tables 12 and 13, if interest were not used in the purchase evaluation, the guaranteed total cost method would have been considered cheaper and would have resulted in a fictitiously low

TABLE 10

LOWEST GUARANTEED TOTAL COST BID FOR 15 MOTOR GRADERS

Cost Elements	Amount
Initial price	26,448.00
Interest compounded at 4 percent ($216 per $1,000)	5,712.77
Guaranteed maximum parts cost	700.00
Total initial price	32,860.77
Guaranteed repurchase price at 5 years or 6,350 hours (whichever comes first)	19,042.00
Net bid price	13,818.77
Hours used for 5-year period[a]	6,350
Net costs per hour	2.1761

Source: Completed forms of Bid Inquiry of the Virginia Department of Highways.

[a]Five years was used in guaranteed cost bidding because suppliers could not secure a bid bond for a greater length of time.

TABLE 11

PROJECTED COSTS OF LOWEST INITIAL PRICE BID AND COSTS OF GRADERS PURCHASED

Costs Elements	Amount
Initial price	14,591.00
Interest compounded at 4 percent ($480 per $1,000)	7,003.68
Estimated parts cost (28 cents an hour for 12,700 hours)	3,556.00
Total initial costs	25,150.68
Estimated resale value at end of 10 years (9 percent of initial price)	1,313.19
Net total cost	23,837.49
Hours used for 10-year period	12,700
Net costs per hour	1.8770

Source: Completed forms of Bid Inquiry of the Virginia Department of Highways.

TABLE 12

LOWEST GUARANTEED TOTAL COST BID EXCLUDING CONSIDERATION OF INTEREST FACTOR

Cost Elements	Amount
Initial price	26,448.00
Guaranteed maximum parts cost	700.00
Total initial price	27,148.00
Guaranteed repurchase price at 5 years or 6,350 hours (whichever comes first)	19,042.00
Net bid price	8,106.00
Hours used for 5-year period[a]	6,350
Net costs per hour	1.2765

Source: Completed forms of Bid Inquiry of the Virginia Department of Highways.

[a]Five years was used in guaranteed cost bidding because suppliers could not secure a bid bond for a greater length of time.

statement of costs and an improper management decision. In addition, by excluding interest the total costs resulting from either the projected initial price bid or the guaranteed total cost bid would have represented only 60 to 70 percent of the true costs.

Furthermore, this mistake probably would have been repeated several times, would have cost the Virginia Department of Highways hundreds of thousands of dollars that could have been used for road construction, and could have created an illusion of substantial dollar savings.

It is recognized that, except for the rapid decline in resale value in the last 5 years, obsolescence was not considered in the total cost bidding formulas. It is the author's opinion, however, that the increased resale value of the projected initial bid price method (plus the reduced parts cost) would have yielded at least a level of 30 percent of initial price or a $10,000 net bid price figure based on a $14,591 initial price projected over a 5-year rather than a 10-year period.

In this case approximately $3,800 per grader would have been saved over the lowest guaranteed total cost method, or still approximately $50,000 for 15 graders. The question of replacing graders every 5 years was brought to the attention of the department, but feeling was that this was not desirable solely on the grounds of considerations of obsolescence. This opinion was confirmed by the suppliers themselves in that they felt secure in guaranteeing lower overall total costs on a 10-year basis but could not do so because of the time limitation on bid bonds as well as (in some cases only) unstable dealer-manufacturer relationships. If, however, another state examines this problem it is the opinion of the author that the question of equipment obsolescence might be reexamined from the standpoint of optimum timing of equipment replacement rather than from the viewpoint of purchasing bidding procedure.

Further reflecting on the study and subsequent events led to the suggestion that total cost purchasing does not necessarily require the awarding of the bid to the supplier that offers the lowest guaranteed total 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 versus lowest guaranteed total costs). The principle of total cost bidding is, however, viewed as sound provided that the purchaser (a) knows his costs of operation under his current purchasing procedures, (b) includes interest in his calculations, (c) compares results of alternative methods of purchase, and (d) does not accept "total cost" formulas until their implications have been thoroughly evaluated. In addition, guaranteed total costs may be

TABLE 13

PROJECTED COSTS OF LOWEST INITIAL PRICE BID EXCLUDING CONSIDERATION OF INTEREST FACTOR

Cost Elements	Amount
Initial price	14,591.00
Estimated parts cost (28 cents an hour for 12,700 hours)	3,556.00
Total initial costs	18,147.00
Estimated resale value at end of 10 years (9 percent of initial price)	1,313.19
Net total cost	16,833.81
Hours used for 10-year period	12,700
Net costs per hour	1.3254

more favorable to a purchaser of dozers and loaders because of greater similarity in initial prices of different brands of this equipment than exists in those of different brands of motor graders.

DISCUSSION OF REVIEWER'S COMMENTS

The following comments were received by the author from reviews requested by the sponsoring Highway Research Board Committee (the reviewers are unknown to the author and therefore are not cited):

> I believe the author needs to explain in more detail the reference he has made to interest costs. In reviewing this paper, I am left at a loss as to the full determination of the interest costs referred to in his analysis. Otherwise a very excellent report.
>
> Loss of time due to delay in delivery parts was not sufficiently stressed.
>
> Interest was figured on a 5-year basis and compared with costs where interest was figured for 10 years was shown as market value whereas the value could be expected to be greater as a trade-in.

It is apparent that there was some misunderstanding of interest costs from what was intended. In an effort to clarify these costs the following is offered.

At the time of the recommendation of adoption of the alternate bids (1965), interest on tax exempt bonds was viewed as 4 percent. It was felt that, because the Commonwealth of Virginia was tying up cash (particularly on a high initial price, high guaranteed repurchase price basis), an estimate of the costs of capital should be made. These costs were viewed in interest terms, and as a result most conservatively, because they could be viewed in terms of alternate returns on investment, which is estimated to be at least 10 percent on Virginia's highway investment.

Interest was also used to prevent the suppliers from establishing an artificially high initial price (thereby using Virginia funds for their own capital ventures for 5 years) with an artificially high guaranteed repurchasing price. This in fact would have been the result had not the costs of capital (viewed as 4 percent interest) been incorporated in the formula for evaluating alternate bids.

Interest was figured on a 5-year basis when evaluating 5-year guaranteed repurchase bids and on a 10-year basis when projecting total hourly costs of the lowest initial price bids.

The guaranteed bids could be guaranteed on only a 5-year basis (because of limitations of supplier or "bonder" capability) and so should not be evaluated on the basis of 10-year interest costs because these costs were apportioned to only one-half the number of hours as interest costs on the lowest initial price bid.

Because it was found most economical for the state to keep equipment on a 10-year basis (if buying for ownership), the lowest initial price bid was projected in this manner. It should be recognized that the true costs are costs per operating hour whether on a 5-year or 10-year basis, and this would naturally result in higher interest costs for the 10-year projected bid but higher repurchase values on the 5-year bid.

After 10 years the value of equipment was deemed at market (not trade-in) value because 10 years is considered to be the complete life cycle of a grader—at least for Virginia's usage. Furthermore, if past experience means anything, a higher initial price for a grader 10 years hence would probably more than offset any difference between market and trade-in value.

Tables 4 and 5 and the accompanying narrative recognize the significance of loss of time due to delay in delivery parts. As a matter of fact these delays were deemed so significant by the author that it was recommended to the management of the Virginia Department of Highways that no more than 5 days' delay should be tolerated, and very high punitive costs should be incorporated in department specifications for delays extending beyond this period of time. Upon reflection, however, it is admitted that perhaps 5 days does not sufficiently stress this loss of time, and the number of days' delay allowed for in the specifications should be reduced.

In conclusion the author is a bit concerned about the misunderstanding in interest cost considerations as these seemed more "obvious" (perhaps the author's style has unnecessarily "muddied the waters"); he is most grateful for the comments relating to repair parts delay and feels compelled to agree, at least in part, with the reviewer's statement on this latter subject.

ACKNOWLEDGMENTS

The principal researchers in the study were Ira F. Doom of the Virginia Highway Research Council and A. C. Baird of the Purchasing Division of the Virginia Department of Highways. All references to researchers mean these individuals.

The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.

Discussion

R. E. EDWARDS, Caterpillar Tractor Company—The Virginia study was initiated in 1965 to determine how to purchase dozers, loaders, and graders at the lowest overall cost to the Virginia Department of Highways. Data collection and analysis, however, were restricted to motor graders because of the time available and the difficulty in obtaining detailed cost data on the equipment. Bids for fifteen 125 hp motor graders were called for by the state in April 1968.

Based on the preliminary results of the Virginia study, suppliers were asked to bid conventional low initial price or guaranteed total cost or both; the state then reduced the low initial price bids to cost per hour of operation through a formula developed by Mr. Doom. Because owning and operating costs were not guaranteed in the conventional low initial price bids, the state had to use past records to estimate these costs. According to the Virginia study, comparing these cost per hour figures with the guaranteed total cost figures would allow the state to purchase graders at the lowest overall cost. The method used in the study compared guaranteed total cost bids on a 5-year basis with low initial price bids, modified by the state, on a 10-year basis. Total cost bid evaluation was limited to 5 years because this was the maximum number of years for which bid bonds could be obtained.

The major contention of the Virginia study is that a false impression of total cost is created unless investment cost (interest) is included in the total cost calculation. In the study, an interest rate of 4 percent was selected in an effort to include foregone interest. "This rate was based on the, then appropriate, rate of tax exempt bonds."

The inclusion of interest is often an important consideration when analyzing alternative investment decisions. However, in this particular case, the decision is not what alternative investment should be selected but what make of motor grader should the State of Virginia purchase. The choice is not between a motor grader and a dozer but between 2 motor graders—one offering no guarantees to the user, and the other guaranteeing maximum repair cost and minimum repurchase value. If interest is considered at all in this purchase, it should be considered only on the incremental difference between the initial price of the low bid grader and the total cost grader. This can be accomplished by evaluating what the additional investment will provide in terms of return on investment.

In making this decision, it is very difficult to assign a monetary value to the guarantees of the total cost bid. On the other hand, it is difficult to ignore the increase in value these guarantees add to the total cost bid grader. Mr. Doom has elected to overlook any relationship these guarantees have with cost of machine ownership and instead has chosen to analyze the bids on the basis of selected cost variables.

In order to select the cost variables to be used in evaluating machine purchases, the Virginia study first identified the factors relevant to motor grader costs: initial price; resale value; parts cost; labor costs; cost of capital (interest cost); obsolescence, insurance, and convenience; service and parts distribution capabilities and policies of the supplier; total hours used; and maintenance practices of the user. However, the Virginia study concludes: "Although all these costs are relevant in evaluating overall hourly equipment costs, only initial price, cost of capital (interest), repair parts, and the resale value depend on the specific brand of equipment purchased."

This arbitrary reduction in cost variables limits the study's capability to determine total costs, primarily because a significant portion of actual machine operating expenses have been excluded. By eliminating these factors, the Virginia experiment with total cost bidding assumes that items of cost such as repair, labor, and downtime caused by delay in parts delivery are not significant expenses. In reality, these expenses can account for a sizable portion of the actual cost of owning heavy equipment and are included in most total cost bids.

Elimination of labor and downtime from the bid prevented a completely realistic evaluation of total costs. To protect the machine owner against excessive downtime, most total cost bid specifications include a stringent parts delivery penalty clause. Mr. Doom recommended to the State of Virginia the inclusion of a 5-day penalty clause but, in fact, such a clause was not included in the final Virginia specifications and was therefore not included in the analysis of the alternative bids.

A review of the Virginia study reveals some additional shortcomings.

1. The Virginia study, which was utilized in 1968 to evaluate motor grader bids over the period of 1968 to 1978, assumes that parts cost are constant (based on figures computed during the years 1958 through 1965). In reality, when costs are projected over future time periods, sizable adjustments must be made to compensate for inflationary effects. The total cost bid, on the other hand, included a guaranteed figure for parts cost over the period from 1968 to 1973.

2. The Virginia study assumes that motor grader usage and availability will be uniform over the entire 10-year period (i.e., 6,350 hours for 5 years, and 12,700 hours for 10 years). In reality, the average hours motor graders are used tends to decrease with age, particularly during the second 5 years. In addition, operating costs for "low initial price" motor graders during the sixth through tenth year can be expected to increase sharply. By comparison, motor graders purchased under guaranteed total cost would never be older than 5 years.

3. The major importance of the guarantees inherent in a total cost bid seems to have been overlooked by the Virginia study. It should have been made absolutely clear that, in a total cost bid, maximum parts cost and minimum repurchase price are completely guaranteed in writing and covered by a performance bond. This is contrasted with the low initial price bid that includes absolutely no guarantees on the "estimated" parts cost and "estimated" resale value. A powerful and persuasive argument in favor of total cost bidding is the protection offered by the total cost bid guarantees against excessive parts cost, and rapid depreciation associated with "low initial price" heavy machinery. These guarantees constitute an insurance against loss; therefore, some consideration of value should be associated with this protection.

The approach and conclusion of the Virginia study do not provide truly valid answers to the problem of purchasing motor graders. In spite of significant differences in initial price, the guaranteed total cost method can still produce important savings. These savings will increase when purchasing heavy machinery with greater similarity in initial price.

Perhaps the greatest shortcoming of the study is that it gives the impression, on the basis of one bid and one analysis, that all total cost bids for motor graders are more costly than low initial price bids. The overall impression given by the Virginia study is that total cost bidding is not the best way to buy motor graders, but no substantial evidence is presented to indicate that total cost bidding is generally more costly. The Virginia study contains the following major deficiencies:

1. Comparison of alternate investments over unlike periods of time by reducing the cost to an hourly basis without giving full consideration to the effect of compounding money over different time periods;
2. Elimination of labor, downtime, and parts delivery capability from the cost analysis;
3. Failure to consider price inflation, along with parts cost data, in analyzing the low initial price bid;
4. Assuming that motor grader usage and availability will remain uniform over a 10-year period; and
5. Overlooking the major importance of the guarantees inherent in a total cost bid.

Total cost purchasing is now being widely used in the United States by many progressive governmental agencies. In the past 6 years, governmental bodies in 45 of the 50 states have begun using this purchasing system. To date, more than 800 pieces of heavy equipment, representing roughly $20 million, have been bought by 400 governmental bodies, ranging in size from the federal government to small municipalities. State highway departments in Maine, Florida, California, and Arizona are using total cost purchasing successfully. We compliment the state of Virginia on its extensive study and evaluation of alternate methods of purchasing heavy equipment, but feel most sincerely that the results thus far are incomplete and should not form the basis for any firm conclusions. After further study and analysis, we feel confident that the state of Virginia will also become an enthusiastic supporter of total cost purchasing on all types of heavy equipment.

IRA F. DOOM, Closure—I shall comment on what I believe are the major points raised in Mr. Edwards' review of my paper and make additional observations that I believe to be pertinent to the subject of total cost purchasing.

The suggestion that a selection between dozers and graders represents an alternate investment decision but that a selection between alternate brands of graders does not appears to indicate some confusion regarding the nature of investment decisions. Alternate investment decisions are based on the different uses of funds, grader versus dozer or grader A versus grader B, and so interest considerations should be included in the evaluation of either alternative. I agreee that "inclusion of interest is often an important consideration when analyzing alternate investment decisions," and therefore suggest that interest should be considered when evaluating alternative investments between graders.

In further consideration of alternate investments, a return on investment factor (estimated to be more than 10 percent on Virginia's highways) rather than interest might logically have been used. Use of such a factor of course would have detrimental effects on the supplier with high initial prices—Caterpillar, for example, in the case of graders.

The implication that the reduction of alternate investments over unlike periods of times to cost per hour terms was unfair is surprising, because this was done to accommodate those suppliers—including Caterpillar—who could not guarantee total costs for more than 5 years as an alternate to state equipment ownership. Efforts to accommodate these suppliers so as to ensure them equal treatment are summarized in the last section of the paper as follows:

> The guaranteed bids could be guaranteed on only a 5-year basis (because of limitations of supplier or "bonder" capability) and so should not be evaluated on the basis of 10-year interest costs because these costs were apportioned to only one-half the number of hours as interest costs on the lowest initial price bid.
>
> Because it was found most economical for the state to keep equipment on a 10-year basis (if buying for ownership), the lowest initial price bid was projected in this manner. It should be recognized that the true costs are costs per operating hour whether on a 5-year or 10-year basis, and this would naturally result in higher interest costs for the 10-year projected bid but higher repurchase values on the 5-year bid.

An additional point concerning interest raised by the reviewer is most significant in that on the surface it appears plausible but the consequences of contract agreement would be most unfavorable to the buyer. The statement made by the reviewer is as follows: "If interest is considered at all in this purchase, it should be considered only on the incremental difference between the initial price of the low bid grader and the total cost grader. [Low initial bid and lowest total cost may be the same and certainly are not mutually exclusive.] This can be accomplished by evaluating what the additional investment will provide in terms of return on investment." In numerical terms his suggestion means that, if the initial price of one grader is $14,000 and that of another is $25,000 (approximately the spread between Caterpillar and the lowest overall total cost grader purchased), only $11,000 interest should be considered. This procedure assumes that money is free, or at least $28,000 of $39,000 is, and from a personal point of view I would very much like to agree with Mr. Edwards but I am afraid such an assumption is unrealistic.

Downtime was not, as he states, assumed to be insignificant but rather was treated separately in the paper in a full section. Recommendations were made to provide penalty clauses for delays in parts delivery beyond 5 business days. Also, in response to Highway Research Board reviewers, the following was stated in the last section:

> Tables 4 and 5 and the accompanying narrative recognize the significance of loss of time due to delay in delivery of parts. As a matter of fact these delays were deemed so significant by the author that it was recommended to the management of the Virginia Department of Highways that no more than 5 days' delay should be tolerated, and very high punitive costs should be incorporated in department specifications for delays extending beyond this period of time. Upon reflection, however, it is admitted that perhaps 5 days does not sufficiently stress this loss of time and the number of days' delay allowed for in the specifications should be reduced.

The bid proposal stated that "prompt delivery of repair parts will be expected", and so Virginia did in fact take into account repair parts delivery in its evaluation in contrast with Mr. Edwards' implications.

Labor costs were assumed to be equal between the state and the supplier but not "insignificant" as stated in the review.

The costs of ordinary repair parts (wearable items) were not included because those suppliers who were interested in bidding under the guaranteed method said that wear of ordinary parts depended on the state of maintenance and they (including Caterpillar) could not guarantee these costs. This fact is recognized by the statements: "Supplies of wearable items represent the principal expenditures of the two [wearable items and parts] but could not be practically taken into account in cost evaluation. This was because none of the suppliers was willing to guarantee supply costs, contending they were directly dependent on grader usage rather than on grader quality." It is a bit disappointing to be criticized for making accommodations to the guaranteed bidding method ("total cost bidding" in Mr. Edwards' terms) by a representative of a company whose representatives had previously stated that without such accommodation guaranteed bidding would be placed at a disadvantage. As a matter of fact, if Virginia had insisted on guarantees on wearable item costs, this would have precluded the Caterpillar Tractor Company from bidding at all, or at least this is what Virginia was told by Caterpillar representatives at the time.

The statement regarding the failure to consider inflation is correct. If inflation is considered as Mr. Edwards suggests, parts costs would increase over time but so would the initial price of a second grader at the end of 5 years. If both parts and initial price were taken into "inflation account", this would almost certainly be to the disadvantage of Caterpillar, because its initial price offers a much bigger inflationary base than do parts costs—at least if Caterpillar's guarantee was anywhere near realistic.

The implied question of obsolescence is a good one—maybe graders should be replaced at 7 or 8 instead of 10 years; but operating costs were not assumed to be constant, as Mr. Edwards implies, because in taking into account repair costs we used 4- to 7-year averages, not 10-year averages. This is stated more specifically in the paper.

The value of a guarantee depends of course on what is guaranteed. In this case, the risks of ownership were assessed by actual records of past experience so that leasing versus ownership, as well as different brands of graders, could be evaluated; the costs in this instance proved to be less for ownership. In addition, those wishing to guarantee bids up to 10 years, including Caterpillar, were given the opportunity to do so but stated they could not. Furthermore, Mr. Edwards' implication that low initial price heavy machinery has excessive parts costs and rapid depreciation may be true in some instances, but certainly not in all. (If this line of reasoning is followed to its ultimate conclusion, the quality of equipment can be raised merely by raising the price of this equipment!)

The author did not intend to give the impression that total cost bids for motor graders or any other piece of equipment are bad, but merely referred to a particular bid in 1965. In addition, this impression should not have been gathered from reading the paper; the paper states, "The principle of total cost bidding is sound as long as it is accompanied by a detailed analysis of the purchaser's current costs, a comparison of guaranteed costs with current costs, an examination of the interests of potential suppliers, the inclusion of the interest factor, and provisions ensuring speedy parts delivery in order to prevent unnecessary and expensive downtime.... In addition guaranteed total costs may be more favorable to a purchaser of dozers and loaders because of greater similarity in initial prices between different brands of equipment than in those of different brands of motor graders."

A final comment is related to both the state of Virginia and total cost purchasing. Virginia was the first state to initiate performance purchasing of tires, and it initiated as well formal studies on total cost purchasing.

It is pointed out that the lowest guaranteed total cost bid does not necessarily result in the lowest purchasing costs in total cost terms. In other words, total cost bidding and total cost purchasing are not necessarily the same in all instances, as Mr. Edwards implies. Total cost bidding (guaranteed leasing arrangement) is merely an alternative to ownership in attempting to achieve the least overall costs. In some cases leasing will be more favorable, while in others ownership will be to the buyer's and/or user's advantage.

Furthermore, it of course makes good sense for Caterpillar to want to omit interest or return on investment considerations from government buying decisions, and to include resale values. This is because it is at a competitive disadvantage on the one hand and has a competitive advantage on the other.

If Virginia should choose to exclude both interest and the possibility of ownership, this would be unfair to Virginia as well as to most suppliers, and total cost purchasing must be just that—not total cost bidding as dictated to Caterpillar's advantage and tailored to Caterpillar's assets, which are considerable, and ignoring the liabilities of its competitive situation.

This does not mean to say that Virginia's alternate bidding formula will be the best in the future either. Obsolescence, performance assessment, timing of equipment replacement, rates of equipment usage, and pooled purchasing agreements are areas of investigation that I believe should improve the state of the art of total cost purchasing.

Effect of Studded Tires on the Durability of Road Surfacing

J. HODE KEYSER, Ecole Polytechnique, University of Montreal, and Control and Research Laboratory, City of Montreal

In Sweden where 60 percent of all vehicles are equipped with studded tires, the pavements are badly deteriorating through wear. The Swedish Road Administration estimates that the cost of wear in 1968-69 amounted to several million dollars. Skid tests made by the Swedish Road Research Institute show that studded tires are effective on icy surfaces near freezing temperature but not so on sanded icy surfaces, packed snow, or very cold ice. Studies made in the laboratory and outdoors on an experimental road track indicate that (a) bituminous mixtures topped with precoated chippings showed much better resistance to wear by studded tires than bituminous concrete and fine stone-filled sheet mats and (b) portland cement pavements also suffer severe wear. The wear rate however diminishes gradually as the coarse aggregates become exposed on the surface and finally decreases several times in comparison to the initial traffic period.

A literature survey and special studies show that studded tires are gaining popularity in the northern part of the United States and Canada. Wear rate of pavements in Montreal by ordinary tires have been determined. Factors affecting wear rate and desirable characteristics of bituminous mixtures have been identified.

•IN THE LAST FEW YEARS we have witnessed the increasing use of studded tires on the American continent and in particular in the northern part of the United States and Canada. The highway and materials engineers have not yet felt the full impact of the problem that will confront them in the next few years with respect to the accelerated wear of pavement surfacings. In Sweden, the highway and municipal authorities are already very much aware of the rapid deterioration of pavements. The problem is so serious that the Swedish authorities are studying at the same time, the effect of wear and the means of repair.

This report is intended to underline the seriousness of the wear problem in North America. The content is divided in 2 parts: The first part outlines the results of investigations made in Sweden concerning pavement wear and skidding. It also includes the results of laboratory and field tests concerning the resistance to wear of different types of surfacing material and their eventual repair. The second part discusses the time trend in the use of studded tires, factors influencing wear, and the desirable characteristics of bituminous overlays designed to resist wear. The discussion is based on a literature review and field observations in Montreal and Stockholm.

OUTLINE OF THE RESULTS OF INVESTIGATIONS MADE IN SWEDEN

The Extent of Pavement Wear

In the Scandinavian countries studded tires have been used since 1959; they became more widespread in 1964 and were in general use by 1966. It was in 1965 that their

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Paper sponsored by Task Force on Effect of Studded Tires and presented at the 49th Annual Meeting.

Figure 1. Premature wear by studded tires of pavements submitted to traffic of high density.

Figure 2. Base course mix appearing through the surface mix.

effect on pavement wear was noticed. The present accepted general use of the studded tire shows that (during a period of 2 or 3 years) a pavement carrying heavy traffic can be so heavily damaged or worn down that the binder coarse and in some cases even the base coarse becomes visible. This abnormal wear of pavements by studded tires has suddenly become the main concern of people associated with road construction and maintenance.

The drastic conditions prevailing in Sweden are confirmed by the following facts: (a) the Swedish National Road Administration estimates that in 1969, with 60 percent of the vehicles equipped with studded tires, the cost of wear reached $7 million; (b) studies undertaken by the city of Stockholm in collaboration with the Bituminous Concrete Association FBB on the wear of road surfacings show that on highways carrying heavy traffic the wear varies between ¼ and ¾ in. and that the average wear exceeds ½ in.; and (c) contractors and road builders will not guarantee the life of surfacings for a period exceeding 2 years.

Figure 1 shows a highway carrying heavy traffic of 40,000 vehicles a day. The rough texture of the binder coarse, clearly visible in the wheelpath of each lane, is in sharp contrast with the fine texture of the adjacent wearing coarse. Figure 2 is a close-up view of the same surface.

Figure 3 shows the extreme wear of a bituminous mixture in the wheelpath. Note that the wear is uneven across the surface. Figure 4 shows that in some areas the bituminous pavement is worn down to the bituminous foundation layer.

A correlation established between the rate of wear from figures obtained in Sweden and an anticipated wear in the United States and Canada would not be realistic for 2 reasons: First, most vehicles in Sweden are equipped with 4 studded tires, and each

Figure 3. Variation in amount of wear across the road.

Figure 4. Extreme wear of bituminous mixture along the wheel track.

tire has from 120 to 140 studs; in the United States and Canada nearly all vehicles have 2 studded tires and from 75 to 100 studs per tire. Second, many secondary roads that are narrow and not surfaced with high-type bituminous mixtures carry an appreciable percentage of heavy traffic.

Confronted with the problem of rapid wear of roads by studded tires, the Swedish Road Research Institute, in collaboration with the Asphalt and Concrete Association, the National Road Administration, the municipal road departments, and contractors, has initiated several studies that can be classified into 3 categories: (a) influence of studded tires on skidding; (b) resistance of various types of surfacings to wear by studs; and (c) means of repairing damages caused by studded tires to highway surface coarse.

Effect of Studded Tires on Skidding

The main purpose of the use of studs is to increase safety by diminishing the stopping distance, in other words, to increase the coefficient of friction between the tires and the pavement. Many studies made by different organizations show that the stopping distance is a complex function of temperature, speed, tire brand, number and configuration of studs, stud protrusions, and other undetermined factors. During the years 1963-1964, the National Road Research Institute of Sweden conducted a large number of tests to determine the influence of studded tires on skidding. Most of the skid resistance measurements were obtained by using a vehicle specially designed for this purpose. The general conclusions of practical interest drawn from these studies are as follows:

1. Studded tires offer a much better skid resistance on icy roads than ordinary snow tires. However, as data given in Table 1 show, resistance to skidding is only slightly improved on sanded icy roads or on packed snow.
2. Skid resistance does not increase proportionally with the number of studs in the tire. Generally, 100 to 200 studs per tire are considered a sufficient number.
3. The coefficient of friction of a studded tire on a dry pavement is from 15 to 20 percent lower than the coefficient of friction of an ordinary tire over the same surface.
4. The directional stability of a vehicle braking on a pavement whether icy or not can be improved if the 4 tires are equipped with studs; on the other hand, it is reduced if only the rear wheels are equipped with studded tires.

Resistance of Different Types of Surfacing to Wear

Three important studies are presently being conducted: (a) laboratory study of the performance at low temperature of different types of surfacings subjected to wear by studded tires (30, 31); (b) study of the performance of different types of surfacings subjected to wear by studded tires on an experimental road (29); (c) study of field performance of highway pavements.

Laboratory Study—The laboratory study consists of evaluating the relative performance of different types of surfacings on a circular track, 18 ft in diameter under the action of wheels equipped with studded tires. The 6-wheel circular machine, shown in Figure 5, is mounted in a cold room. The circular track is composed of 7 concrete elements topped with different types of surfacings. Tests are conducted on a wet course at a speed of 24 mph (35 km/h) and at a temperature ranging from 32 to 41 F (0 to 5 C). Only 2 wheels are used for the tests. The amount of wear is measured after 200,000 passes of studded tires (7.50 by 14 in.) inflated at 27 psi (1.9 kp/cm^2). The load on the wheel is 1,155 lb (525 kp).

When the test was conducted with ordiary tires, practically no wear was noticed.

TABLE 1

SKID RESISTANCE OF NONSTUDDED AND STUDDED TIRES

Surface Condition	Coefficient of Friction	
	Nonstudded Tires	Studded Tires[a]
Plane surface covered with fresh ice	0.10	0.25 to 0.30[b]
Sanded icy surface	0.40	0.45 to 0.50
Surface with packed snow	0.30	0.35 to 0.45[c]

[a]Test results are not affected by the wear of studs on 10,000 km (6,250 miles of dry pavement surface).
[b]60 to 120 tube-tipped studs or 100 to 170 sharp-pointed studs.
[c]100 to 200 sharp-pointed studs.

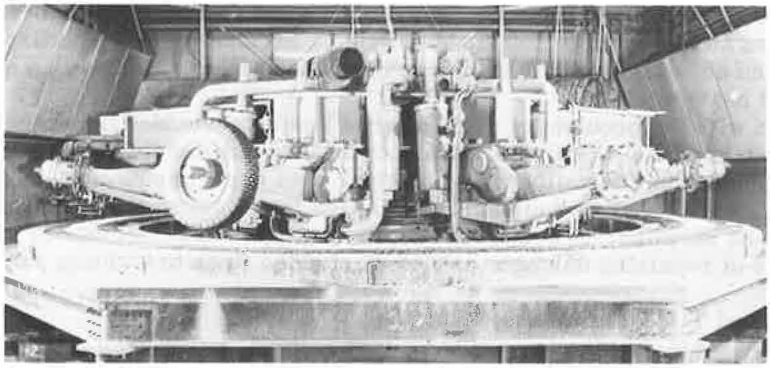

Figure 5. Four-wheel circular machine used by the Swedish Road Research Laboratory for tests.

The following results were obtained after 200,000 passes of studded tires:

1. Topeka or rolled asphalt-type bituminous surfacing, which is similar to a fine-graded stone-filled sheet asphalt with an excess amount of fines and topped with asphalt precoated aggregates of a uniform size, gave better results. The wear varied between 2.0 and 6.0 mm (0.08 and 0.24 in.). Aggregates used in the mix and for the topping were of igneous origin. The binder used was an 80 penetration grade bitumen.
2. Asphaltic concrete made with coal tar precoated aggregates also gave good results. The wear measured varied between 4.0 and 6.5 mm (0.15 and 0.26 in.).
3. On ordinary asphalt surfacings (no treatment with precoated aggregates), the wear varied between 6.0 and 10.5 mm (0.24 and 0.41 in.).

Portland cement concrete also suffered severe wear (Fig. 6). On old concrete, a 4.5-mm wear (0.18 in.) was noticed after 200,000 passes. On new concrete, the wear varied between 5 and 9 mm for the first 200,000 passes and between 1 and 3 mm for the subsequent 200,000 passes.

Experimental Roads—The experimental road was built on Broma Airport grounds by Swedish National Road Research Institute in collaboration with the engineering department of the city of Stockholm. The track layout and the remote control vehicle (a Volvo-Duett station wagon) are shown in Figure 7. Each wheel has 144 studs arranged in 6 parallel rows in contact with the road. The running track is divided into 8 sections of 150 ft each. Each section has a different surfacing. The data given

Figure 6. Wear of concrete surfacing by studded tires.

Figure 7. Remote control vehicle on experimental road.

TABLE 2

RELATIVE PERFORMANCE OF DIFFERENT TYPES OF BITUMINOUS OVERLAY

Section	Type of Mix	Quantity		Penetration Grade of Bitumen	Relative Wear After 50,000 Passes of Vehicle or 100,000 Passes of Studded Tires
		kg/m²	lb/sq yd		
1	Topeka	80	145	80	37
2	Bituminous concrete	80	145	80	46
3	Bituminous concrete made with coal tar precoated coarse aggregate	80	145	80	38
4	Bituminous concrete made with coal tar precoated coarse aggregate	60	108	200	60
5	Bituminous concrete	60	108	200	63
6	Topeka with precoated chipping	80	145	80	37

TABLE 3

TYPICAL GRADING OF TOPEKA AND BITUMINOUS MIXTURE

Sieve Size	Topeka[a] (percent passing)	Bituminous Concrete[b] (percent passing)	Sieve Size	Topeka[a] (percent passing)	Bituminous Concrete[b] (percent passing)
¾ in.		98	No. 16	68	32
⅝ in.	100	96	No. 30	60	24
⅜ in.	95	80	No. 50	47	18
No. 4	72	57	No. 100	30	14
No. 8	70	40	No. 200	19	10

[a]7.5 to 8.5 percent bitumen content. [b]7.0 percent bitumen content.

in Table 2 show that the best results were obtained by a bituminous concrete or Topeka made with 85 to 100 penetration grade bitumen covered with precoated coarse aggregates. Note that much more wear was obtained with mixtures made with 200 penetration grade bitumen. Table 3 gives the grading of the mixtures.

Figure 8 shows the spreading of precoated chippings on a Topeka surfacing mix. Figure 9 is a close-up view of a pavement surface treated with precoated chippings.

Field Performance of Roads—Figures 1, 2, 3, and 4 show that the performance of roads not topped with precoated chippings was very bad. On streets with extra heavy traffic, the top course, which is generally 3 cm (1.2 in.) thick, was completely worn down in the wheelpath after a few years. In special traffic areas such as at braking, accelerating, or turning points, the pavement was worn down to the base course, which is usually 6 to 8 cm (2.4 to 3.2 in.) below the surface level.

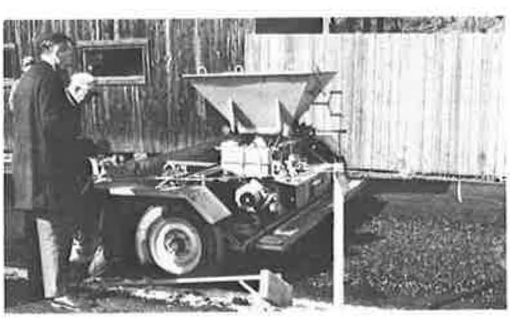

Figure 8. Spreading of precoated chippings on a Topeka surfacing mix.

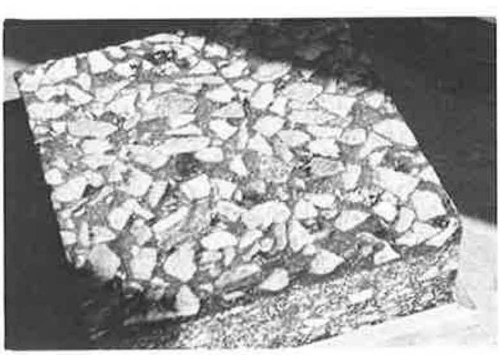

Figure 9. Close view of a section of pavement surface treated with precoated chippings.

TABLE 4

FIELD TEST VARIABLES

Bituminous Mixture		Precoated Chippings			
Type	Asphalt	Type	Size	Bitumen 80-100	Rate of Spread
Topeka	7.8 percent, 80-100	Granite, Sinopal, labradorite, quartzite, gravel	1/4-1/2 1/2-5/8 5/16-1/2 5/16-9/16	1.0 1.5 2.5	4-7 15
	1:3 Tar: 80-100 (8.1 percent)	Granite	1/4-1/2 5/16-9/16	1.7 percent bit. + 1.5 filler	7 15
	1:1 Lake asphalt: 85-100 (9.2 percent)	Granite	1/4-1/2	2 percent lake asphalt + 1.5 filler	7 15
Bituminous concrete	7.3 percent, 80-100	Granite, labradorite, quartzite, Sinopal	5/16-1/2 5/16-9/16	1.5 percent bit. 1.5 percent bit. + 1.5 percent filler	15

Given the fact that laboratory tests have conclusively shown that wear rate can considerably decrease by spreading precoated chippings on bituminous surface layer, 38 different test strips were built on 3 urban highways by the cities of Stockholm and Malmö in collaboration with the Swedish Association for Bituminous Pavements (FBB) to evaluate which type of bituminous surface and precoated chipping would be the most resistant to wear and skidding. The test variables, given in Table 4, are the type of bituminous overlay on which precoated chippings are spread, the type and amount of bituminous binder in the mix, the type and size of aggregate used as precoated chipping, the type of material used to precoat the chippings, and the rate of spread of the precoated chippings.

Different construction procedures were used for the construction of test strips. In one case, the mixtures were laid with a spreader and the precoated chippings were spread by hand immediately behind the asphalt spreader. A 10-ton steel roller was used for the breakdown rolling, then a pneumatic tire roller having a tire pressure of 3 km/cm^2 (42.6 lb/in.^{2}) was used for the intermediate rolling, and the same steel roller was again used for the final rolling.

In another case the precoated chippings were spread by a macadam spreader and the rolling was accomplished by 2 passes of a pneumatic roller with dry hot tires inflated to 1.8 kg/cm^2 (25.6 lb/in.^{2}) followed by a 10-ton steel roller for final rolling aiming at a void content varying between 3 and 4.5 percent.

To prevent lumping and sticking in the spreader, the precoated chipping was not heated but used cold.

Means of Repairing Damages Caused to Highways by Studded Tires

One of the problems with which the Swedish Department of Highways and the municipal public roads departments have to cope is the repair of hundreds of miles of pavement prematurely worn out by studded tires. They are looking for a resurfacing material that is more resistant to wear. The particular feature of these pavements is that wear is concentrated in the wheelpath. In each lane, a 2- to 3-ft wide and 1- to 3-in. deep parabolic depression can be seen. It is most difficult to repair such depressions at low cost, especially if a good appearance and an even compaction are to be attained.

The authorities of the city of Stockholm in collaboration with the FBB are aware of this problem and are making great efforts to solve it. If conventional materials are used, the resurfacing will wear out in about the same short period of time.

In the case of city roads it is not always possible to resurface after the profile has been corrected because a minimum height of 3 to 4 in. for sidewalk curb must be provided. To remove the old layer of surface coarse, the city of Stockholm has experimented with a special machine, shown in Figure 10. The first tests covered just a few miles of pavement and proved to be very satisfactory. The cost is approximately 0.80 cents per sq yd for 1- to 1.5-in. thickness.

Figure 10. Special machine used to remove a given layer of bituminous pavement.

DISCUSSION OF FINDINGS

Time Trend in the Use of Studded Tires

Data obtained from sources listed in the References show conclusively that the use of studded tires in various countries will become more and more widespread in the course of time (Table 5). In Sweden, the percentage of automobiles equipped with studded tires increased from 15 percent in 1964 to 60 percent in 1968. In the northern part of Sweden many trucks are presently equipped with studded tires. The Swedish highway authorities believe that the percentage of automobiles equipped with studded tires will not increase substantially in the future; however, without restrictions being imposed more trucks and buses will eventually be equipped with studded tires. Based on data published in the United States and Canada, the percentage of automobiles equipped with studded tires doubled every year from 1966 to 1968. Given the aggressive sales promotion of the tire manufacturers, it is quite possible that the trend will continue for at least another year. In fact, a survey with garage owners and tire suppliers indicates that at least 50 percent of all winter tires sold in the Montreal region are studded tires.

There are inherent causes that limit the popularity and usefulness of studded tires; they are costly and decrease the driving safety on a bare pavement at high speeds. These factors limit their use, and a balance will soon be reached. Studies conducted in Sweden and elsewhere (5 through 14) clearly established that studded tires are effective on icy surfaces but of little or no value on sanded icy surfaces or packed snow. On bare pavements the studded tire has an adverse effect.

For example, the Public Roads Department of the city of Montreal uses each year for the maintenance of its 1,000 miles of city pavements approximately 10,000 tons of

TABLE 5

USE OF STUDDED TIRES IN DIFFERENT COUNTRIES

Country, State, or Province	Reference	Percent of Cars Equipped With Studded Tires				
		1964	1966	1967	1968	1969
Ontario[a]	33		2	8	18	
Quebec autoroutes[a]	39		9	22	47	50+
Quebec parking lots[a]	39		6	18	28	35
Finland[b]	36		67	70		85
Sweden[b]		15			60	
Norway	38					60-70
Minnesota[a]	32	4	9	23	32	~40

[a]Rear wheels only. [b]Front and rear wheels.

abrasive sand and 88,000 tons of de-icing salt. The pavements are very rarely covered with ice (only a few hours per year).

Wear of Pavement Surface

A pavement surface constructed with high-quality portland cement concrete or high-type bituminous mixtures will normally, during its anticipated life, resist the abrasive action of traffic without excessive wear. Premature disintegration of the pavement surface by wear is generally experienced in an area of abnormal heavy traffic such as on steep slopes and at sharp turns and curves. The pavement surface will also deteriorate if the surfacing materials are not durable, for example, non-air-entrained concrete subject to frost action, bituminous or portland cement concrete prepared with unsound aggregates, bituminous overlays containing a very low amount of voids in mineral aggregate, and a too high voids content. In the latter case, the action of traffic accelerates a surface deterioration but is not the main cause.

The results of a survey made to estimate the rate of wear of pavements by traffic in Montreal are given in Table 6. Studies undertaken in Sweden indicate that the rate of wear of surfacings by studded tires is ½ in. per year on roads carrying an average daily traffic of 40,000 vehicles. This represents a serious durability problem.

Until recently the wear of pavements was mainly associated with the frequency and magnitude of truck wheel loads expressed in terms of a "common traffic denominator" such as design traffic number or axle load equivalency factor. However, with automobiles equipped with studded tires, the average daily traffic becomes an important factor.

A comprehensive literature review made to identify factors that affect pavement wear by studded tires and their relative importance is given in Table 7. The sources are listed in the References. The many factors and their combinations affecting wear must be defined for each set of conditions. For example, Wehner shows in his road test results that the mean wear depth of all pavements after 27,000 passes with unloaded vehicles is about twice as severe for negative acceleration (from -10 to -15 ft/sec^2) than for positive acceleration (5 to 10 ft/sec^2). Wear measurements made at 21 toll booths of the Montreal-Laurentians Autoroute indicate that the wear depth was about twice as great for acceleration 20 ft after stopping than deceleration 20 ft before stopping (Table 8). This simply shows that unless the cause of wear is clearly defined according to the prevailing conditions the results obtained with different conditions might be inexact and even contradictory.

Results of wear measurements obtained from 6 different sources are given in Table 9. Because test parameters are not well defined, the results cannot be correlated. Nevertheless, the variability in the results obtained indicates that wear is a function of well-defined and limited conditions.

TABLE 6

NORMAL RATE OF WEAR OF PAVEMENTS BY TRAFFIC (NO STUDDED TIRES) IN MONTREAL

Traffic Condition	DTN[a]	Mix Type[b]	Time in Years Required to Wear ½ in.	
			Straight	Intersection[c]
Light	<10	All	>30	>20
Medium	10-100	All	>20	>15
Heavy	100-1,000	All	>15	<10
Extra heavy	>1,000	Sheet	4-5	2.5-4
		Stone-filled	5-10	3-4

[a]The design traffic number is the actual daily number of equivalent single axle load applications in a traffic lane.

[b]All mixes are dense graded with a Marshall stability in excess of 1,000 lb and voids in mix less than 8 percent.

[c]Round points, start, stop, sharp turn.

TABLE 7

FACTORS AFFECTING PAVEMENT WEAR

Factor	Component	Characteristic
Vehicle, tire, and stud	Vehicle	Type and weight
		Axle load
		Number of studded tires (front, rear)
	Tire	Type (snow or regular with or without stud receiving holes)
		Pneumatic pressure
		Age
		Configuration of studs
		Number of studs
	Stud	Type (material, shape)
		Protrusion length
		Orientation of studs with respect to tire wear
	Stud wear versus tire wear	
Pavement	Geometry	Cornering (curve, sharp turn)
		Straight section
		Intersection
		Slope (up and down)
	Surfacing material	Type and characteristics (bituminous mixtures, surface treatment, precoated chipping, portland cement, hardness)
		Age
	Surface condition	Surface texture and profile
		Icy
		Compacted snow (compactness)
		Sanded or salted icy surface
		Slush
Environment	Humidity, temperature	Wet, dry, humid
Traffic	Volume	Number of passes and composition
	Speed	
	Wheel track	Width
		Distribution of wheel load
	Contact mode	Start (normal, abrupt)
		Stop (normal, abrupt)
		Acceleration (rate)
		Deceleration (rate)
		Spin
		Skid
Measure	Method and precision	

Resistance of Pavement Surfacing Material to Wear

When a wheel spins or skids, the studs made of hard tungsten carbide steel scarify the surface with grooves of rectangular cross section. Because approximately 90 percent of the surface material is composed of aggregates, the relative depth of the groove is a function of both the hardness of the stud and aggregate material and the amount of contact pressure. The type of marking depends on the amount of cutting force exerted by the wheel on the pavement.

In the case of portland cement concrete, the groove depth or attrition rate depends on the hardness of the aggregate and the quality of the mortar. As a rule the soft thin layer of a new concrete pavement will wear by attrition more rapidly at the beginning and then decrease as the harder polished aggregate becomes more and more apparent on the surface.

When an automobile moves on a level pavement at constant speed, the studs penetrate the bituminous surface forming cylindrical indentations. The wall of the cylindrical indentation then becomes less

TABLE 8

WEAR OF CONCRETE PAVEMENT AT TOLLBOOTHS

Tollbooth	Maximum Wear Depth (in.)		Wear Ratio	Mean Wear Ratio
	Start (Acceleration)	Stop (Deceleration)		
1-N	0.49	0.28	1.75	1.72
2-N	0.53	0.42	1.26	
3-N	0.49	0.42	1.17	
4-N	0.98	0.49	2.00	
5-N	0.91	0.63	1.44	
6-N	0.95	0.35	2.71	
6-S	1.26	0.39	3.23	2.27
5-S	1.22	0.63	1.94	
4-S	1.40	0.70	2.00	
3-S	0.56	0.21	2.67	
2-S	0.49	0.42	1.17	
1-S	0.91	0.35	2.60	

TABLE 9

SUMMARY OF TESTS ON WEAR OF PAVEMENT SURFACE BY STUDDED TIRES

Vehicle	Load (lb)			Studs		Tire Pres-sure	Temp.	Speed (mph)	Geometry	Track Width (in.)	Volume	Contact Mode	Pave-ment	Wear (in.)
	Front Wheel	Rear Wheel	Total	Front Wheel	Rear Wheel									
White and Jenkins (16)[a]														
Pickup	1,300	1,700	6,000	72	72	—	—	15-20	Straight	12	10,660	Normal	BC	0.25
								10-15	Curve, r = 36 ft	18-24	5,330	Acceleration	BC	0.11
												Deceleration	BC	0.18
Burke and McKenzie (17)														
Automobile	—	—	—	—	52	—	—	—	—	—	25	Rapid start	PCC	0.04
Tessier and Normand (23)														
Automobile	—	—	—	90	120	—	0-40	55	Straight	36	33,500	Normal	BC	0.068
Lee, Page, and DeCarra (20)[b]														
Truck	3,500	4,000 (2)	23,000	110	110	—	12-65	40	Straight and curve	30	10,000	Normal	BC	0.086
													PCC	0.054
Automobile	400	900	2,600	104	104	—	18-67	40	Straight	30	10,000	Normal	BC	0.068
													PCC	0.018
Bellis and Dempster (19)														
Automobile	700	700	2,800	50-32	50-32	30	—	20 max	Straight	—	4,990	Normal acceleration	BC	0.026
													PCC	0.032
												Abrupt stop	BC	0.02
													PCC	0.01
												Emergency stop	BC	0.056
													PCC	0.015

[a]Acceleration:deceleration ratio = 1.6.
[b]Truck BC:truck PCC ratio = 1.6; automobile BC:automobile PCC = 3.8; PCC truck:PCC automobile ratio = 3.0; and BC truck:BC automobile ratio = 1.3.

TABLE 10

DESIRABLE CHARACTERISTICS OF BITUMINOUS OVERLAY TO RESIST WEAR BY STUDDED TIRES

Causes of Wear	Desirable Characteristics	Suggested Tests
Cutting and attrition of coarse aggregates and mixtures	Hard aggregates Aggregates of smooth surface texture Mix of close texture	Measure of the hardness of aggregate surface Los Angeles abrasion test Texture of coarse aggregate
Pullout of aggregates	Good adhesion between aggregate and bitumen High specific surface of coarse aggregate Mix of close surface texture	Immersion-compression test Stripping test Determination of the sphericity of particles Grading of mix
Fracture of coarse aggregate under the pressure of studs	Aggregate of high strength Aggregate of cubical shape	Compression test of aggregate Shape of particles
Indentation of studs in the bituminous mixture and shear	High resistance to indentation Mortar as stable as possible Minimum percentage of mortar High filler-bitumen ratio	Resistance to penetration of filler-bitumen-sand mixture Coarse to fine aggregate ratio Grading of fines Grading of mix; degree of compaction of pavement

stable than the original material. The amount of wear by indentation is related to 2 major factors: (a) the relative area of aggregate exposed on the surface to the total area, and (b) the hardness of the fine aggregate-filler-bitumen mortar.

Studies made by the Swedish Road Research Institute show conclusively that a Topeka or bituminous concrete mixture topped with precoated chippings was considerably more resistant to wear than an ordinarily designed mix. A mixture made with a 200 penetration grade asphalt was less resistant than a mixture made with an 80 penetration grade asphalt.

Table 10 gives a tentative list of desirable characteristics for bituminous overlays in order to resist wear by studded tires, and a list of conventional tests that could be used to establish design criteria.

Research is needed, however, to establish a relation between wear and the durability characteristics as measured by a given test. The values or factors thus determined could then be used to establish design criteria for surface material resistant to wear.

CONCLUSIONS

The following conclusions are drawn from observations made in Sweden and a comprehensive review of literature.

1. In countries not imposing restriction on studded tires, their use is becoming more and more widespread with time. The percentage of automobiles equipped with studded tires reached 85 percent in Scandinavian countries and 50 percent in some parts of the United States and Canada. An increase in the number of buses and trucks equipped with studded tires is also anticipated.
2. The need for studded tires depends on the winter pavement condition and maintenance practice. In urban areas where the pavement is nearly always bare or sanded the overall beneficial effect of studded tires is questionable, mainly because it decreases the driving safety on bare pavement, causes premature wear of pavement, and leaves a depression along the wheelpath that in turn becomes a driving hazard.
3. Laboratory study and experimental road and field test results have shown that resistance to wear can be increased by spreading precoated chippings on bituminous material before rolling and by using a stiffer binder.
4. Wear rate of pavement not subjected to stud action is established for different traffic conditions.
5. Wear rate must be defined for each set of conditions. Factors affecting the pavement wear have been obtained from observations made in Sweden and Montreal and from a literature review.
6. The resistance to wear of bituminous material is related to the type of wear. Desirable characteristics and related possible conventional tests that could be used are listed.

7. There is an urgent need to undertake studies (a) to determine factors influencing wear and to estimate the rate of wear under defined conditions; (b) to establish surface mix design criteria for pavement materials that will better resist wearing action; (c) to find means to minimize damage to new pavements and to protect the old ones; and (d) to find effective and economical means of repairing damaged pavements.

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REFERENCES

Characteristics of Studded Tires

1. Miller, W. P., II. The Winter Tire Stud. Highway Research Record 136, 1966, pp. 1-6.
2. Miller, W. P., II. Principles of Winter Tire Studs. Highway Research Record 171, 1967, pp. 1-13.
3. Krick, L. H. Studded Tires. American Highway, 1966.
4. Report on Tire Studs for Passenger Cars. Kennametal Corp., Pa., 1964.

Performance of Studded Tires on Ice

5. Kullberg, G., and Ohlsson, E. Report 38, Swedish National Road Institute.
6. Passenger Car and Friction—Trailer Tests. Committee on Winter Driving Hazards, National Safety Council, Stevens Point, Wis. Final reports, 1965 and 1966.
7. Salosis, J. L. A., and Cousins, A. R. Evaluation-Studded Tires. RCAF Central Experimental and Proving Establishment, Report 1782, 1965.
8. Easton, A. H. Performance of Studded Tires on Ice. Highway Research Record 136, 1966, p. 7.
9. Pulley, A. L., and Dell'Amito, F. Performance of Studded Tires on Ice. CAL Report V1-2204-V-I, 1966.
10. Burnett, W. B., and Kearney, E. J. Studded Tires—Skid Resistance and Pavement Damage. Highway Research Record 136, 1966, pp. 24-30.
11. Whitehurst, E. A., and Easton, A. H. An Evaluation of Studded Tire Performance. Highway Research Record 171, 1966, pp. 14-27.
12. Bellis, W. R., and Dempster, J. T., Jr. Studded Tire Evaluation in New Jersey. Highway Research Record 171, 1966, pp. 28-51.
13. Bird, K. D., and Rosenthal, P. Measure of Effectiveness of Studded Tires. Cornell Aeronautical Laboratory, 1968.
14. Tests on Studded Tires by National Swedish Road Research Institute, 1969. Summary Report presented to the Highway Research Board, 1969.

Effect of Studded Tires on Highway Pavement

15. Jensen, P. A., and Korfhage, G. R. Preliminary Studies of Effect of Studded Tires on Highway Pavements. Highway Research Record 136, 1966, pp. 8-23.
16. White, O. A., and Jenkins, J. C. Test of Steel Studded Snow Tires. Highway Research Record 136, 1966, pp. 31-41.
17. Burke, J. E., and McKenzie, L. J. Some Tests of Studded Tires in Illinois. Highway Research Record 136, 1966, pp. 42-58.
18. Burnett, W. B., and Kearney, E. J. Studded Tires—Skid Resistance and Pavement Damage. Highway Research Record 136, 1966, pp. 24-30.

19. Bellis W. R., and Dempster, J. T., Jr. Studded Tire Evaluation in New Jersey. Highway Research Record 171, 1966, pp. 28-51.
20. Lee, A., Page, T. A., and DeCarrera, R. Effects of Carbide Studded Tires on Roadway Surfaces. Highway Research Record 136, 1966, pp. 59-77.
21. Wehner, B. Wear of Road Surfaces by Winter Tires With Spikes/Beanspruching der Strassenoberflaeche durch Winterreifen mit Spikes. Technische Universität Berlin, 1966.
22. Hultala, Matti. The Wearing Effects of Studded Tires on Certain Asphalt Pavements. The State Institute for Technical Research, Helsinki, Finland, 1967.
23. Tessier, G. R., and Normand, J. Les pneus à crampons et leurs effets sur une chaussée souple. Canadian Technical Asphalt Assn., 1967.
24. Hogbin, L. E. Damage to Roads by Studded Tires. Road Research Laboratory, Harmondsworth, England, RRL Report LT208, 1968.
25. Tests on Studded Tires by National Swedish Road Research Institute, 1969. Summary Report presented to the Highway Research Board, 1969.
26. Schonfeld, R., and Smith, P. Present and Predicted Pavement Wear in Ontario by Studded Tires. Department of Highways, Ontario, 1969.
27. Smith, P. The Cost of Damage by Studded Tires Over the Next Ten Years in Ontario. Department of Highways, Ontario, 1969.
28. Peffekoven, W. Laboratory Investigations of the Abrasion of Asphalt Pavements Under Studded Tires. Koninklijke/Shell Laboratory, Amsterdam, 1969.
29. Anderson, O., and Lilja, B. Road Wear Due to Studded Tires—Measurements of Road Profiles in the Stockholm Area. National Swedish Road Research Institute, 1969.
30. Örbom, B. The Effect on Concrete Pavement of Studded Winter Tires. The National Swedish Road Research Institute, 1969.
31. Anderson, O., Lilja, B., Rosengren, A., Astrom, T., and Örbom, B. Pavement Wear Due to Studded Tires Measured in the Test Road Machine of the National Swedish Road Research Institute. National Swedish Road Research Institute, Spec. Rept. 83A, 1969.
32. Preus, C. K. Effect of Studded Tires on Aggregate Wear Rate and Related Effects on Skid Resistance. Minnesota Department of Highways, 1970.
33. Smith, P., and Schonfeld, R. Pavement Wear Due to Studded Tires and the Economic Consequences in Ontario. Department of Highways, Ontario, DHO Rept. RR152, 1969.
34. Wehner, B. Surface Wear in Relation to Type of Tires. Proc. Thirteenth Congress of Permanent Internat. Assn. of Road Congresses, 1967.
35. Untersuchungen über den Verschleiss an Strassenoberflächen durch Winterreifen mit Spikes. Technische Universität Berlin, 1968.
36. Soveri, U. Studded Tires—A Problem in Finland. The State Institute of Technical Research, Finland, 1969.
37. Soveri, U. The Use of Studded Tires and the Wearing of Surfacing in Finland, 1969.
38. Moe, T. T. Pavement Wear Caused by Use of Studded Tires and Chains. Norwegian State Road Laboratory, 1970.

General

39. Doucet, R. Effets des pneus à crampons sur l'usure des revêtements des chaussées. Présenté au congrès de l'Association Québecoise des Techniques Routières, 1969.
40. Factors Involved in the Design of Asphaltic Pavement Surfaces. NCHRP Rept. 39, 1967.
41. Rosenthal, P., Haselton, F. R., Bird, K. D., and Joseph, P. J. Evaluation of Studded Tires (Performance Data and Pavement Wear Measurement). NCHRP Rept. 61, 1969.
42. Trend in Use of Studded Tires. Minnesota Department of Highways, 1969.
43. Rosengren, A. An Investigation Concerning Studded Tires With Special Reference to Pavement Wear, Based on Literature Studies. The National Swedish Road Research Institute, Spec. Rept. 81A, 1969.

Pavement Wear Due to Studded Tires and the Economic Consequences in Ontario

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The wear caused by studded tires has been measured on different pavement surfaces in Ontario by using a simple photographic method to record before-and-after cross-sectional profiles. Results show that, with not more than 20 percent of vehicles using studded tires, substantial wear has occurred during one winter of moderate-to-heavy traffic. Estimates of future pavement wear indicate that a serious problem has to be faced for which no lasting and economical repair or preventive procedures yet exist. Experience in Europe and North America is reviewed in an effort to compare any benefits of studded tires with the widely reported pavement damage they may cause. The alternative courses of action—to restrict the use of studs or to allow their continued use—are considered in the light of the findings.

•STUDDED TIRES have become increasingly popular during the last few years as an aid to winter driving. They afford appreciable improvements in vehicle braking, cornering, and traction on ice; limited benefits are experienced on packed snow, but no advantages are obtained on bare pavements. Studded tires are mostly used on passenger cars where they may be fitted on all 4 wheels or, more usually, in North America, on the rear wheels only. The studs (between 100 and 150 per tire) are set in the tires with about $\frac{1}{16}$ in. of the tungsten carbide tip protruding from the tread. Because stud wear occurs at approximately the same rate as the tire wear, this projection remains about the same throughout the life of the studs. After a few thousand miles of driving, especially on bare pavements, the tips of the studs become beveled and their effectiveness diminishes. Few studs are lost from the tire by normal driving, but they may be ejected occasionally by violent starting.

The beneficial action of studs is achieved through their ability to indent the surface of ice and packed snow. Unfortunately, they are also capable of cutting and wearing away the surface of bare pavements. Furthermore, unlike tire chains, which are only used intermittently when actually needed, studded tires are kept on the car throughout the winter, and most of the time they are running on clear, dry pavement.

Studded tires originated in Finland in 1959, and from 1962 their use has increased rapidly in northern Europe. In Sweden the number of passenger vehicles equipped with studs has increased from 15 percent in 1964 to 60 percent in 1968. From 1964 onward, unusually severe pavement wear was observed in many northern European countries, and considerable work has been carried out to determine the causes and to find more wear-resistant pavement surfaces.

No lasting solution to the problem of wear has so far been found in Europe. In some countries the use of studded tires is discouraged by restricting their use or prohibiting them; but in others with more severe winter conditions, such as Norway, Sweden, and Finland, the wide-scale use of studded tires continues on passenger cars and has extended to trucks and buses.

Not surprisingly, a similar trend is developing in the northern United States and Canada. Studs were first introduced to this continent in 1963, and since then their use

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has increased each winter. In 1968-69, New York, Minnesota, and Manitoba reported that 20 to 25 percent of passenger cars were fitted with studded tires, while in Quebec and the Maritime Provinces, the figure was 50 percent or more in some locations. Several states and provinces, including New York, Minnesota, Wisconsin, Michigan, Quebec, Manitoba, New Brunswick, and Nova Scotia, have recently reported unusual damage to pavements ranging from local wear where vehicles stop, start, or turn to more general wear on the highway (1).

The use of studded tires is permitted in Ontario from October 1 to April 30, provided they are fitted to all wheels or both rear wheels; they cannot be used on the front wheels only. Their use has increased rapidly on passenger cars though none has, as yet, been noticed on heavier vehicles. Surveys of parked vehicles (at the Department of Highways headquarters in Toronto) showed that 2 percent of cars were equipped with studded tires in 1966-67, 8 percent in 1967-68, and 18 percent in 1968-69. A limited province-wide survey made at the end of the winter of 1968-69 revealed that between 2 and 27 percent of the vehicles on the roads were using studded tires; the percentage varied with geographical location, and the province-wide average was 14 percent. This growth pattern fits those observed in Minnesota and Sweden and indicates that 60 percent of the cars in Ontario may be equipped with studded tires by the winter of 1971-72.

Unusual wear was first observed on the MacDonald Cartier Freeway (Highway 401, Toronto Bypass) and in the town of Huntsville after the winter of 1967-68. As a result, a program was established to measure and evaluate the effects of studded tires on both bituminous and portland cement concrete pavements over the 1968-69 winter period.

The measurements made indicate that significant wear occurred in Ontario during one winter that fits a pattern of wear observed in Germany and from which a procedure for predicting future wear was developed (2). By applying the same prediction procedure, it is estimated, from the test locations in Ontario, that 1 in. (25 mm) of wear in the wheel tracks will occur within 2 to 5 years on the more heavily traveled roads if the use of studs continues and increases at the expected rate. Where traffic is lighter the wear will take longer to reach serious proportions. In addition to general wear in the wheel tracks, more intense local wear is observed wherever vehicles stop, start, or turn and painted traffic markings disappear within a few weeks after the onset of winter.

This presents a serious problem for the safe operation of traffic and the maintenance of pavements. If the use of studded tires continues, and increases at the expected rate, the question of the extent, type, and cost of remedial treatments and the anticipated life of pavements becomes an important consideration. Accordingly, possible methods of repairing worn pavements are considered together with a means of providing more wear-resistant surfaces. These are itemized and the additional costs that will result over the next decade are developed for the Ontario highway system.

A number of the types of pavement surfaces mentioned in the report may not be generally familiar. A description of their salient features is given in the Appendix.

PRESENT WEAR

Method of Measurement

Most investigators of pavement wear have determined the amount of wear from before-and-after measurements of cross sections of the pavement, and elaborate equipment has been developed to measure and record individual spot depths along the profile (3). For the investigation described in this report, a simple, photographic method was used that produces a continuous profile and a record of the pavement surface texture with a minimum of field work and interruption to traffic flow.

In this method, a thin wire is stretched above the pavement at a fixed height by a supporting frame seated on reference studs countersunk in the pavement surface. The studs are located sufficiently clear of the pavement edge, or any cracks, to avoid differential displacement due to frost heaving. A light-tight box is then placed on the pavement over the stretched wire. A single flash picture, which covers a strip of pavement about 6 in. wide, is taken from a height of 18 in. by using a camera mounted in the top of the box. The flash unit is positioned above and to one side of the wire so that it casts a shadow of the wire on the pavement surface. In order to sharpen the shadow and limit the amount of light, the flash is blanked off to a narrow horizontal slit about $^1/_{16}$ in. wide. A series of photographs is taken by moving the camera-box along the wire. Photographs of the strips of pavement can be repeated at the same location to record progression of wear at whatever time interval is desired. Figure 1 shows the apparatus ready for use.

Figure 2 shows an example of the progression of wear in a concrete surface. As wear progresses the shadow of the wire moves away from the wire by an amount directly proportional to the wear on the pavement surface. The error introduced by any decrease in elevation of light source and camera, as the pavement surface wears, is negligible because the distance to the light source is very large compared with the depth of the wear.

For all practical purposes the oblique cross sections provided by a succession of shadow lines are a sufficiently accurate means of determining pavement wear. From full-size prints or projected slides, the shadow profiles can be measured and used in at least 3 different ways. First, the shortest and longest ordinates between the datum wire and its shadow on the pavement give, after reduction to datum, the least and the greatest profile depth respectively. The differences in these measurements from successive pictures are measures of the minimum and maximum depths of wear. Second, the area between the wire and its shadow can be measured by a planimeter so that the average depth of wear in a particular period can be obtained by dividing the area between successive shadow lines by the length of the wire, as given by the centimeter graduated measuring tape (Fig. 2). Third, by fitting an envelope of appropriate base length touching only the high spots on the shadow profile, a pavement elevation, as might be measured by the foot of a leveling staff, can be obtained.

Measurements Made

Measurements of pavement profiles were made in the fall of 1968 and the spring and fall of 1969 at 53 locations; 43 of these were on the lanes of a core-collector freeway in

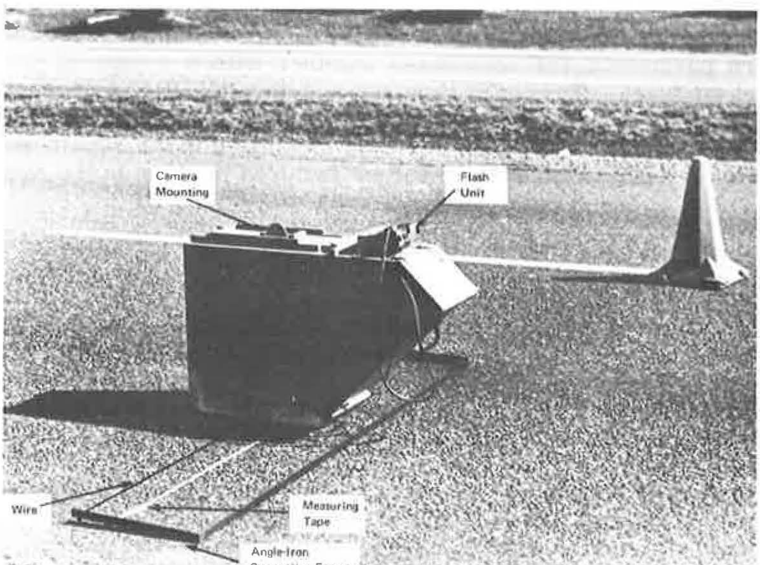
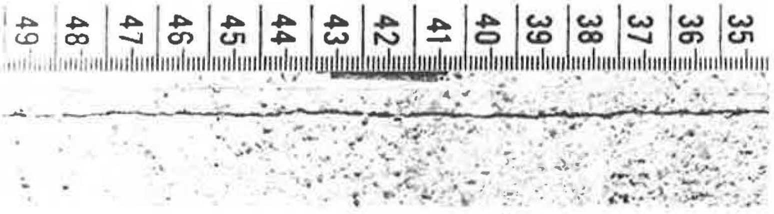
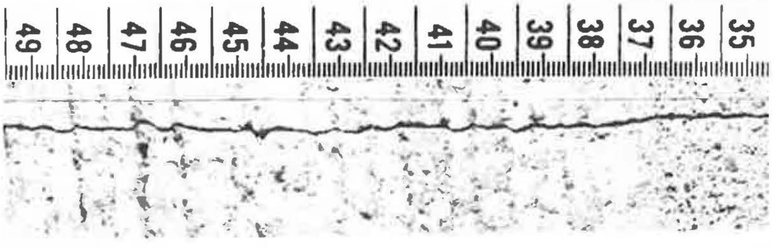


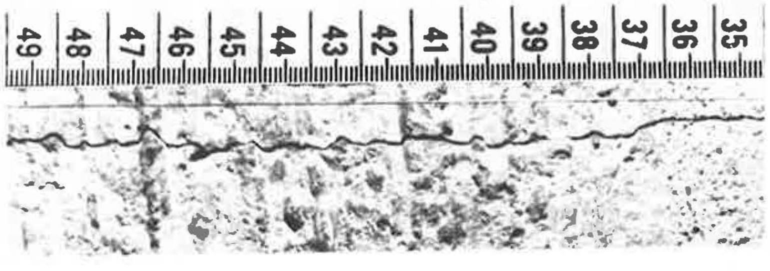
Figure 1. Photographs being taken of a bituminous pavement worn by studded tires (Highway 400, HL1, 1 year old, AADT 5,200 per lane).



INITIAL STAGE



INTERMEDIATE STAGE



FINAL STAGE

NOTES:

1. *Examples are from test track experiments where studs tracked in the same path.*
2. *Scale is in centimeters.*
3. *Unworn surface at extreme right.*

Figure 2. Example of surface wear (concrete) showing increasing distance of shadow from the wire as wear progresses.

Toronto that carried heavy traffic, and the remainder were on major highways having moderate to heavy traffic volumes in southern Ontario. Both bituminous and concrete pavements were measured, and significant differences in the type of wear were detected.

The wear, which occurred during the winter of 1968-69 and corresponding information on the traffic volumes, is given in Table 1. The 1969 fall measurements at the same locations (not reported) indicated that no appreciable wear, due to normal tires, occurred during the summer. Each set of measurements reported was taken from a single profile across the outer wheel track of the pavement lane concerned. No attempt was made to establish repeatability or reproducibility of the measured wear at the

TABLE 1

PAVEMENT WEAR MEASUREMENTS

Location	Pavement Wear[a] in Wheel Track			Pavement		Traffic	
	Avg[b] (mm)	Min[c] (mm)	Max[d] (mm)	Type	Age (yr)	AADT Per Lane[e]	Operating Condition
Highway 401, Toronto Bypass west of Don Valley Parkway, westbound core							
Center Lane	1.89	1.14	2.28	Conc.	1	9,400	Straight, normal freeway
Passing	1.34	0.49	2.28			6,300	driving, maximum
Driving	0.63	0.00	0.95			4,000	speed 70 mph, core-
Center	2.08	0.97	3.42			9,400	collector system
Passing	1.60	0.49	3.04			6,300	
Driving	0.81	0.49	1.71			4,000	
Center	0.85	0.49	1.17			9,400	
Passing	0.80	0.49	1.52			6,300	
Driving	0.18	0.00	1.14			4,000	
Center	0.85	0.49	2.09			9,400	
Passing	1.54	0.97	5.32			6,300	
Driving	1.26	0.97	1.52			4,000	
Center	1.36	0.97	3.15			9,400	
Passing	1.16	0.49	2.18			6,300	
Highway 401, Toronto Bypass east of Avenue Road, eastbound core							
Center Lane	3.39	1.94	5.34	Conc.	3	9,400	Straight, normal freeway
Passing	3.97	2.43	6.55			6,300	driving, maximum
Driving	1.00	0.49	2.91			4,000	speed 70 mph, core-
Center	2.25	0.49	3.40			9,400	collector system
Passing	3.83	1.94	5.58			6,300	
Driving	1.63	0.97	3.40			4,000	
Center	3.35	1.14	3.88			9,400	
Passing	3.55	1.14	5.82			6,300	
Driving	1.28	0.00	2.18			4,000	
Center	4.01	2.43	5.34			9,400	
Passing	3.57	2.91	6.55			6,300	
Driving	1.65	0.49	3.40			4,000	
Center	2.33	0.97	4.12			9,400	
Passing	2.60	1.14	3.88			6,300	
Highway 401, Toronto Bypass east of Spadina Expressway, eastbound core							
Driving Lane	1.12	0.49	1.94	Conc.	3	4,000	Straight, normal freeway
Center	3.04	1.14	3.64			9,400	driving, maximum
Passing	3.35	1.94	4.85			6,300	speed 70 mph, core-
Driving	1.15	0.49	2.43			4,000	collector system
Center	3.03	1.94	3.88			9,400	
Passing	2.94	1.94	4.37			6,300	
Driving	1.47	0.00	2.91			4,000	
Center	2.55	0.49	3.40			9,400	
Passing	3.89	2.43	6.06			6,300	
Driving	1.44	0.97	1.94			4,000	
Center	2.02	0.97	4.12			9,400	
Passing	4.46	2.43	5.82			6,300	
Driving	1.23	0.49	1.94			4,000	
Center	2.63	0.97	4.85			9,400	
Passing	3.49	2.49	4.37			6,300	
Highway 11B, Huntsville, near junction with Highway 527, southbound lane	5.40	0.97	7.28	HL4	5	4,000	City traffic in business section, maximum speed 30 mph
Highway 11B, Huntsville, between King and West Streets							
Southbound lane	5.34	0.97	8.25	HL4	9	4,900	City traffic, maximum
Northbound lane	4.89	0.49	8.73			4,900	speed 30 mph
Highway 126, London, at junction with Highway 401, northwest ramp, northbound lane	1.45	0.00	6.79	HL3	5	2,800	Curve, exit ramp,
	1.46	0.00	2.67				single lane rec.
	1.06	0.00	4.61				speed 50 mph
Highway 401, London, east of Highway 126, eastbound driving lane	1.18	0.00	2.43	HL1	2	6,500	Straight, normal freeway
	2.18	0.00	4.85				driving, maximum
	1.84	0.00	3.40				speed 70 mph, 4-lane
	1.88	0.00	3.88				controlled access
	1.52	0.00	2.91				
Highway 400, Barrie, north of junction with Highway 89, southbound driving lane	1.97	0.24	5.09	HL1	1	5,200	Straight, normal freeway
	2.17	0.24	4.85				driving, maximum speed 70 mph, 4-lane controlled access

[a]The range between minimum and maximum depth of wear is indicative of the relative wear resistance of the different components in the pavement surface. For example, a small range indicates even and uniform wear resistance of both the coarse aggregate and matrix while a substantial range indicates that differential wear is occurring, usually where a hard coarse aggregate is embedded in a softer matrix.

[b]Average depth of pavement wear is the thickness of an imaginary uniform layer that would be occupied by the total volume of material (coarse aggregate and matrix) removed from the pavement surface during the period of time in question. It is an indicator of the overall amount of wear occurring.

[c]Minimum depth of wear is the greatest difference in elevation between the 2 upper envelopes fitting the before-and-after profiles. It generally indicates the extent to which the most wear-resistant component of the pavement surface (usually the coarse aggregate) has been worn and corresponds to the pavement elevation carrying traffic.

[d]Maximum depth of wear is the greatest difference in elevation between the 2 lower envelopes fitting the before-and-after profile. It generally indicates the extent to which the least wear-resistant component of the pavement surface (usually the matrix) has been worn.

[e]Traffic volumes have been tabulated per lane (to give the number of passes of vehicles over the test locations) on this basis: Highway 401 Toronto Bypass, actual counts; Highway 11B Huntsville, ½ total AADT; Highway 401 London and Highway 400 Barrie, 35 percent total AADT. AADT (including commercial vehicles) is given in Table 2.

same spot. The uniformity of the wear along the pavements can, however, be judged where more than one reading is given for the same highway, lane, and traffic volume. In these cases, measuring stations were located some distance apart to represent the sections of highway concerned.

Visual Observations of Unusual Wear

Figures 1 and 3 show the extent of concentrated wear in the wheel tracks that has already occurred widely on bituminous and concrete pavements subjected to heavy traffic in Ontario. Marked local damage of the type shown in Figure 4 has also occurred in many locations where vehicles stop, start, or turn.

One of the most obvious signs that unusual wear is occurring is the general loss of painted traffic lines, often in the first weeks of winter, and particularly on curves. Other examples of unexpected wear were that longitudinal grooves, cut $\frac{1}{8}$ in. deep in concrete pavement to improve skid resistance, were worn completely away in the wheel tracks on curves, and thin bituminous overlays were worn through to the underlying material in some locations in one winter. In other locations the comparatively heavily broomed surface texture, formed in new concrete pavement to provide skid resistance, was worn away during the first winter (Fig. 5). This suggests that where such rapid wear occurs no reliance can be placed on surface texturing as a means of imparting long-term skid resistance to concrete pavements, and also that it is pointless to apply linseed oil to enhance scaling resistance.

Though often striking at first sight, none of the damage noticed had yet reached a critical stage.

Figure 3. Studded tire wear on concrete pavement (Highway 17, Queensway, Ottawa, 6 years old, AADT 10,000 per lane).

Additional Test Track Experiments

Rotary traffic simulators that had been used in another investigation were modified so that they could be run with a load of 1,000 lb on each wheel. Studded tires were fitted on 2 of the simulators to compare the wear on portland cement and bituminous concrete surfaces with that caused by snow tires on the other simulators that were not equipped with studs.

Very rapid wear was caused by the studded tires. The wear, both to the pavement surface (Fig. 2) and to the studs, was not of the same nature as that occurring on the highway. There appeared to be 3 main reasons for this: The studs followed each other in exactly the same tracks, there was some wheel bounce, and there was a constant scuffing action due to the lack of toe-in or camber of the test wheels. The pavement wear recorded for the unstudded tires was so small as to be negligible. The results of these tests were of little real value except to draw attention to the need to align the wheels in small-diameter traffic simulators to ensure true rolling action.

Discussion of Findings

Depending on the location and volume of traffic, the average wear in the wheel tracks during one winter (5 months probable

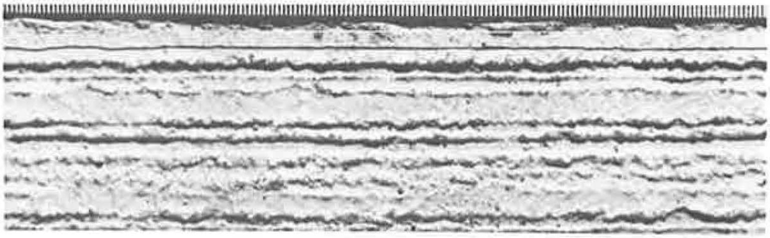
Figure 4. Localized wear at an intersection where vehicles stop, start, and turn.

use of studded tires) ranged from 1.32 mm on an interchange ramp at London with 2,800 vehicles per day to 5.40 mm at Huntsville with 4,000 vehicles per day; both of these were asphalt pavements. On the concrete pavement of the Toronto Bypass, the wear in the wheel tracks ranged from 1.13 mm in the driving lane to 2.67 mm in the passing lane with between 4,000 and 9,400 vehicles using each lane per day. Though the test locations were few in number and were on highways that carry substantial traffic and are bare most of the winter, the results indicate that significant wear can occur on both bituminous and concrete paved lanes where the average annual daily traffic (AADT) is as low as 2,000 passenger cars with probably no more than 20 percent of these vehicles equipped with studded tires.

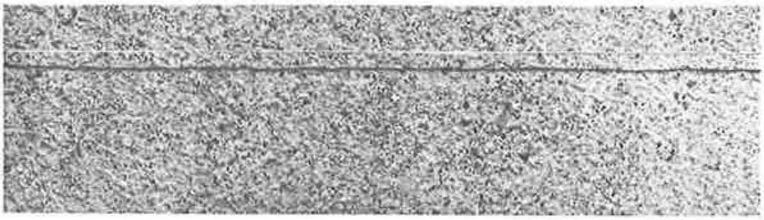
Increased wear occurs with increased traffic volume and at locations where vehicles are required to change speed or direction. In the town of Huntsville, wear increased very noticeably where vehicles stopped and started at traffic lights, turned at intersections, or started on a grade. On the Toronto Bypass, which has a core-collector system providing at least 6 lanes in each direction, wear is generally greater in the passing lanes than in the center lanes, even though traffic is lighter. No facts are available to explain this observation, but it is possible that more cars with studded tires use the passing lanes than the other lanes.

Except where turning movements occur, wear due to studded tires is invariably concentrated in the wheel tracks. This rutting of the pavement is potentially serious because of its effects on the control of vehicle direction. Surface drainage is also impaired, and this leads to ponding, splashing or icy patches, and an increased risk of skidding. Early loss of surface texture on concrete pavements rapidly reduces their skid resistance.

Two basic approaches have been used to compare wear on different pavements and to evaluate the results from test track experiments. The first, as used in this report, is to compare average depths of wear in the wheel tracks. The justification for this is that the point at which pavement surfaces will generally become unserviceable is likely to be dictated by the depth of these ruts. On the other hand, in comparisons of wheel track wear with more general wear that may occur across the whole pavement, or with that on test tracks where the studded tire passes cover only a comparatively narrow band, the conversion of the average depth of wear into a figure representative of the amount of material removed has considerable merit. A procedure for this has been introduced by Anderson of the National Swedish Road Research Institute (7) in which the specific wear (S.P.S.) is calculated as the amount of material in metric tons that would be worn away by one million vehicle-kilometers (the vehicles being equipped with studded tires on all wheels). Rosengren (5) has reviewed most published European and North American data on studded tire wear and has calculated the average depth of wear in the wheel tracks for one million vehicle passes and the S.P.S. values.



a) New Concrete Pavement, Showing Transverse Wire-Broom Texturing to Improve Skid Resistance



b) Concrete Pavement After One Winter's Wear
(initial surface texture has been removed by wear)

c) Concrete Pavement 3 yrs. Old
(uniform wear is proceeding)

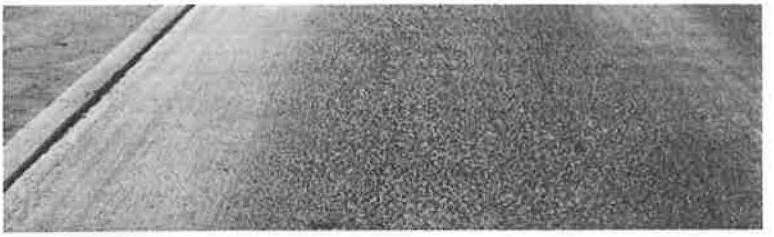
NOTE:

The examples shown are not repeated photographs of the same location, but the concrete in each case, has the same mix proportions and contains soft coarse aggregate. AADT = 9,400 per lane.

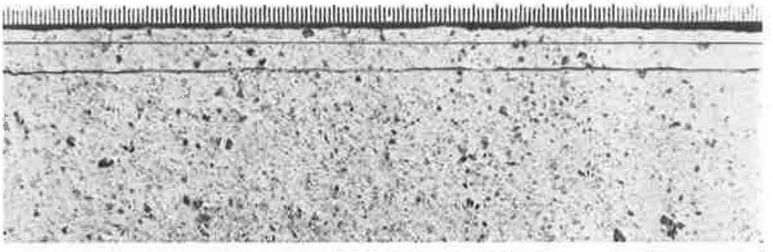
Figure 5. Uniform wear on concrete pavements (Highway 401, Toronto Bypass).

The wear occurring in Ontario can be compared with that currently occurring in Sweden as reviewed by Keyser (4) and elsewhere in northern Europe as reviewed by Rosengren (5). In Sweden, in the city of Stockholm, wear on streets subjected to heavy traffic has exceeded an average of 12.55 mm, and contractors will not guarantee surfacings for longer than 3 years. In Finland the average wear on the most common types of pavement during the winter of 1968-69 was 2.3 mm where 85 percent of passenger cars, 46 percent of trucks, and 47 percent of buses were equipped with studs. This wear was typical of straight sections of 2-lane pavements having an AADT of 4,000 and maintained bare over a 6-month period of stud use. Maximum wear in the wheel tracks was 1.5 to 2.0 times the average wear, and at intersections maximum wear was 4 times the average wear on straight sections. In Norway the average wear during each of the last 2 winters, on the full lane width of roads in Oslo, has been 5 mm with local rutting to a depth of 10 mm. This wear was caused by 60 to 70 percent of passenger cars and 20 percent of heavy trucks having studded tires. Under these conditions the life of pavement surface courses is found to be 3 to 5 years rather than the 8 to 10 years previously experienced.

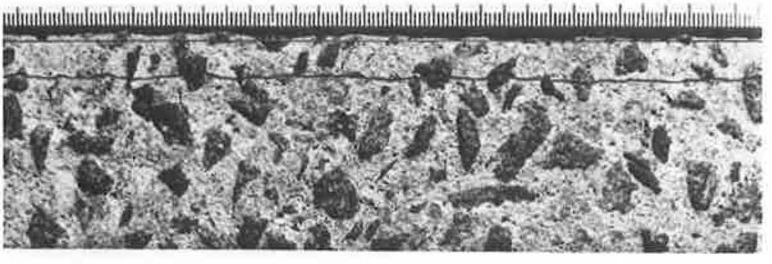
From photographs shown in Figures 5, 6, and 7 and the data given in Table 1 for the ranges between the minimum and maximum depth of wear, it is evident that 2 distinct



a) General View



b) Lightly Worn Area Outside Wheel-Track, Showing Loss of Surface Texture



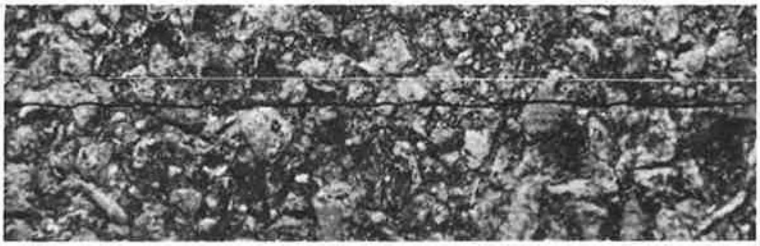
c) Wear in Wheel-Track, Showing Differential Wear between Hard Coarse Aggregate and Softer Matrix

Figure 6. Differential wear after one winter on concrete pavement containing a hard aggregate (experimental pavement, Highway 401, Toronto Bypass, AADT 9,400 per lane).

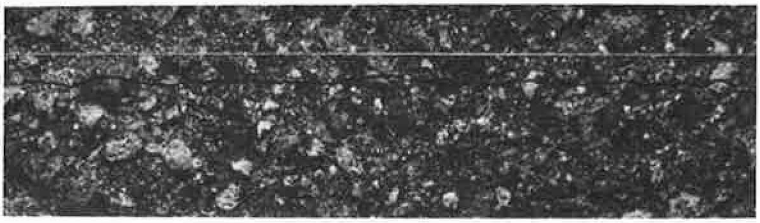
types of pavement wear may occur in Ontario, depending on the wear resistance of the coarse aggregate as compared with that of the matrix in which it is embedded.

The first type of wear is shown in Figure 5 (concrete pavement) and Figure 7a (bituminous pavement). The aggregate in these cases is a soft limestone, and the wear is uniform across the surface; there are no hills and valleys on the shadow profile, and the difference between minimum and maximum wear is very small. The 1-year-old concrete pavement (Fig. 5b), the 3-year-old concrete pavement (Fig. 5c), and the 5-year-old bituminous pavement (Fig. 7a) all show similar uniform wear, which may be expected to continue at a uniform rate.

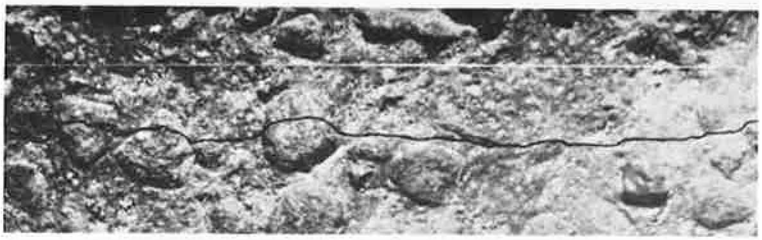
The second type of wear is shown in Figure 6 (concrete pavement) and Figure 7b and c (bituminous pavement). The coarse aggregate in the 3 cases shown was hard and fracture-resistant trap (basalt) or other igneous rock. In the case of the younger pavements, Figure 6c (concrete) and 7b (bituminous), the wear cycle has just started. The beginnings of hills and valleys can be seen on the shadow profile, but as yet there is no great difference between the minimum and maximum wear. Figure 7c, however, shows a much older bituminous pavement containing hard aggregate. The development of



a) Uniform Wear - Soft Aggregate
(Ramp, Hwy. 401 to Hwy. 126 London, AADT 2,800 per lane)
(HL3, 5 years old)



b) Initial Wear - Hard Aggregate
(Hwy. 400 South of Barrie, AADT 5,700 per lane)
(HL 1, 1 year old)



c) HL4 Showing Differential Wear - Hard Aggregate
(Hwy. 11B Huntsville, AADT 4,900 per lane)
(HL4, 9 years old)

Figure 7. Wear on bituminous pavements, showing the effect of hardness of the coarse aggregate.

valleys is visible where the softer matrix has been worn away, and the protruding hard aggregate is quite evident at the left end of the shadow line. This is reflected in large differences between the measured minimum and maximum depths of wear. Toward the right end of the shadow profile, a third stage of the wear cycle is apparent. In this area the matrix is relatively flat and depressed, and there is evidence that coarse particles have been dislodged.

As long as the wear-resistant coarse aggregate remains in place it supports the vehicle tires, so that the studs will eventually be unable to reach and remove further material. With time, however, the coarse aggregate particles are loosened and dislodged by the impact of tires (and studs) and the undercutting of the supporting matrix. When this occurs, there is an abrupt local jump in the recorded wear of the pavement.

It is important to establish if these observations are unique or if others have reached similar conclusions because they greatly influence the estimation of pavement service life and the choice of future surfacings.

Differential wear in bituminous concretes with subsequent loosening and loss of coarse aggregate particles has been reported by Hultala in Finland (6). Anderson et al.(7)

in Sweden have observed that the matrix is relatively more susceptible to wear during the early stages, and once this is worn away the pressure of the studs is taken up mainly by the large size fraction of the aggregate. Peffekoven (8) in Holland, who studied the effect of hardness of the coarse aggregate as an independent variable, concluded that hardness of the aggregate had an overriding influence on wear resistance when compared with other properties of a bituminous mixture. On many surfaces higher initial wear rates were observed with the rate of wear later slowing down (6, 7, 8), but the general dependence of total wear on the number of stud passes, found earlier by Wehner (2), was not disputed.

Confirmation of these findings under highway conditions and the nature of the studded tire wear with the types of materials and mixes in use in North America must await further experimental work and long-term measurements. Meanwhile, the number of passes of studded tires that may be expected to occur has been taken as the governing criteria in predicting future wear on existing pavements.

PREDICTION OF FUTURE WEAR

Although the percentage of vehicles presently using studded tires in Ontario, and the resulting damage, is much less than that reported by others, a substantial amount of pavement wear has been observed, and it is necessary to predict future wear in order to estimate what effect this may have on maintenance requirements in the years to come.

Wehner (2) has reported a linear relationship between the depth of pavement wear and the number of passes of studded tires (the latter being obtained from the AADT and the percentage of vehicles with studs). It is of interest to compare the wear actually measured on the Ontario pavements with calculated estimates of wear, based on Wehner's work.

Table 2 gives the average depth of wear measured at the test locations and the wear calculated by Wehner's method for similar traffic conditions and varying percentages of studded tires. The measured wear, in each case, falls within one standard deviation (approximately 25 percent) of that predicted by calculation for 15 percent studded tires. Although the exact percentage of vehicles with studded tires passing over the test locations is not known, the survey data indicate that it is probably close to 15 percent.

This close correlation justifies using the same relationship to extrapolate the measured wear for one winter to predict future wear on the same pavements. In order to compare the different test locations, the time to produce 1 in. (25 mm) of wear has been calculated. The results are shown in Figure 8 for each test site for 3 different assumed future levels of studded tire use. The assumption thought to be the most probable one is that the use of studded tires will increase from 15 percent (1968-69) to 35 percent (1969-70) to 50 percent (1970-71) to 60 percent (1971-72) with no subsequent increase, while the traffic volume also increases by 5 percent each year. This assumption fits the extrapolation of the Ontario and Minnesota growth curves for studded tire use and coincides with increases that have already occurred in succeeding winters in Scandinavia.

If this assumption is correct, then 1 in. (25 mm) of the surfaces of both bituminous and portland cement concrete pavement will be worn away in the wheel tracks within 2 to 5 years at the heavier trafficked locations. This prediction appears to match the wear occurring in countries such as Norway, Sweden, and Finland as documented in the previous section of this report.

In order to monitor the predictions, rate of wear measurement will be continued each spring and fall at the locations reported. In addition, many other measuring stations have been installed in order to provide better representation of pavement types and ages, traffic volumes, and environmental conditions in southern Ontario.

REPAIR AND PREVENTION OF DAMAGE

If the use of studded tires continues and intensifies, then economical ways must be found for repairing the damage and preventing, or reducing, it on new highways. Experience in restoring pavement surfaces in Ontario is essentially limited to resurfacing

TABLE 2

PROJECTED PAVEMENT WEAR BY STUDDED TIRES, ACTUAL WEAR AND ESTIMATED WEAR, WINTER 1968-1969

Location	Pavement		Traffic		Measured Wear[a] (mm)			Wear (mm)			Calculated Wear Estimate[e]			
	Type	Age	AADT	Maneuver	Min[b]	Max[c]	Avg[d]	Mean	+σ	-σ	Winter ADT Percent of AADT	Adjusted ADT for Wehner's 2-Lane Graph	Percent Studs	Days Used
ighway 401														
Driving lane														
Don Valley	Conc.	1	4,000	Straight	0.37	1.33	0.72	0.7	0.4	0.8	70	4,500	10	120
Avenue Road		3	1-way 1 lane		0.49	2.97	1.39	0.8	0.5	1.1			10	150
Spadina Expressway		3			0.49	2.23	1.28	0.9	0.7	1.3			12	150
						Avg	1.13	1.2	0.8	1.6			15	150
								1.6	1.1	2.1			20	150
Center lane														
Don Valley		1	9,400	Straight	0.81	2.53	1.35	1.5	1.1	1.9	70	10,700	10	120
Avenue Road		3	1-way 1 lane		1.40	4.42	3.07	1.9	1.3	2.4			10	150
Spadina Expressway		3			1.10	3.98	2.65	2.3	1.6	2.9			12	150
						Avg	2.36	2.8	2.0	3.6			15	150
								3.7	2.7	4.8			20	150
Passing lane														
Don Valley		1	6,300	Straight	0.59	2.87	1.29	0.9	0.7	1.3	70	7,100	10	120
Avenue Road		3	1-way 1 lane		1.91	5.68	3.10	1.2	0.8	1.7			10	150
Spadina Expressway		3			2.25	5.09	3.63	1.5	0.9	2.1			12	150
						Avg	2.67	1.9	1.2	2.7			15	150
								2.5	1.6	3.6			20	150
ighway 11B, Huntsville, near junction with Highway 527	Asphalt HL4	5	8,000 2-way 2 lanes	Braking (city traffic)	0.97	7.28	5.40	2.8	2.1	3.7	90	5,800 +25 percent for city traffic = 7,300	10	120
								3.7	2.7	4.7			10	150
								4.5	3.2	5.8			12	150
								5.7	4.0	6.9			15	150
								6.5	4.5	7.9			17	150
								7.7	5.3	9.3			20	150
ighway 11B, Huntsville, between King St. and West St.	Asphalt HL4	9	9,800 2-way 2 lanes	Braking (city traffic)	0.74	8.49	5.34	3.6	2.5	4.9	90	7,100 + 25 percent for city traffic = 9,000	10	120
								4.5	3.2	6.3			10	150
								5.5	3.9	7.7			12	150
								6.8	4.8	8.8			15	150
								7.7	5.5	10.0			17	150
								9.1	6.4	11.6			20	150
ighway 126, London, junction with Highway 401, northwest ramp	Asphalt HL3	5	2,800 1-way 1 lane	Curve	0.00	4.69	1.32	0.5	0.3	0.7	70	3,000	10	120
								0.7	0.4	1.0			10	150
								0.8	0.5	1.1			12	150
								0.9	0.7	1.1			15	150
								1.1	0.8	1.4			17	150
								1.3	0.9	1.7			20	150
ighway 401, London, eastbound, east of Highway 126	Asphalt HL1	2	18,700 2-way 4 lanes	Straight	0.00	3.49	1.72	0.8	0.5	0.9	70	5,300	10	120
								0.9	0.7	1.2			10	150
								1.1	0.8	1.5			12	150
								1.3	0.9	1.7			15	150
								1.6	1.1	2.0			17	150
								1.9	1.3	2.4			20	150
ighway 400, Barrie, southbound, north of junction with Highway 89	Asphalt HL1	1	15,000 2-way 4 lanes	Straight	0.24	4.92	2.07	0.8	0.5	0.9	70	5,400	10	120
								0.9	0.7	1.2			10	150
								1.1	0.8	1.5			12	150
								1.3	0.9	1.7			15	150
								1.6	1.1	2.0			17	150
								1.9	1.3	2.4			20	150

he range between minimum and maximum depth of wear is indicative of the relative wear resistance of the different components in the pavement surface. For example, a small range indicates even and niform wear resistance of both the coarse aggregate and matrix while a substantial range indicates that differential wear is occurring, usually where a hard coarse aggregate is embedded in a softer matrix.
verage depth of pavement wear is the thickness of an imaginary uniform layer that would be occupied by the total value of material (coarse aggregate and matrix) removed from the pavement surface uring the period of time in question. It is an indicator of the overall amount of wear occurring.
linimum depth of wear is the greatest difference in elevation between the 2 upper envelopes fitting the before-and-after profiles. It generally indicates the extent to which the most wear-resistant component of the pavement surface (usually the coarse aggregate) has been worn and corresponds to the pavement elevation carrying traffic.
aximum depth of wear is the greatest difference in elevation between the 2 lower envelopes fitting the before-and-after profile. It generally indicates the extent to which the least wear-resistant component of the pavement surface (usually the matrix) has been worn.
ased on Wehner (2) using correction factors suggested by Wehner for 20 percent commercial vehicles without studs, lower winter traffic volumes, duration of ice and snow cover, and actual traffic test track passes of studded tires.

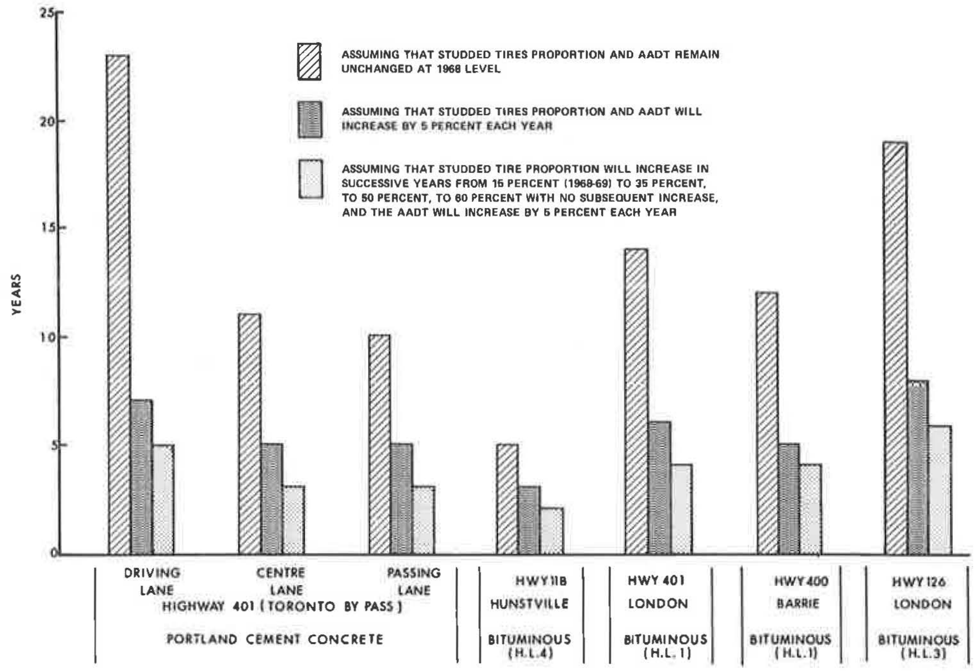


Figure 8. Number of winters for studded tire use to cause 1 in. of wear.

with a bituminous overlay. This technique is not applicable, without modification, to repair of damage caused by studded tires, for the following reasons:

1. If conventional materials are used, the resurfacing will wear out in the same short period of time (much of the locally available aggregate in southern Ontario is derived from relatively soft sedimentary rocks; harder igneous rocks predominate further north).
2. Wear is likely to be localized in the wheel tracks, possibly only in one lane. The whole width of a road, or even lane, may not require resurfacing. No economical way of repairing this kind of longitudinal rutting is yet available.
3. Concrete patching of worn wheel tracks on a concrete pavement would be difficult and expensive and would cause serious delays to traffic. It is unlikely, however, that a concrete pavement repaired by filling the rutted wheel paths with asphaltic material would be acceptable.

Furthermore there is little local or other North American experience on which to draw for the improved wear-resistant surfacing materials that will be required for use on both repair work and new construction, and for ways of providing more lasting traffic markings on pavements. In Europe, however, considerable experimental work has already been carried out. From a review of European findings and those apparent so far in the Ontario investigation, a reasonably clear idea can be gained of what may be required. Consequently, several trial sections of pavement and traffic markings have been laid to evaluate some of the alternative materials that might resist the wearing effects of the prevailing studded tire traffic.

Wear-Resistant Pavement Surfaces

Although stud damage to pavements seemingly cannot be entirely prevented, it might be reduced if more wear-resistant surfaces could be developed and used in both repair work and new construction. The properties required to produce these surfaces in bituminous pavements have so far only been investigated to a limited extent, mostly in

Europe and mainly under simulated wear conditions, although some field trials have been undertaken. For conventional densely graded bituminous mixes, there appears to be general agreement that both increased stone content and hardness significantly improve wear resistance (5, 6, 7, 8, 9). Some correlation is indicated between wear resistance and the Los Angeles abrasion loss of the coarse aggregate (5). The influence of binder content and viscosity is less clear. One investigation (8) found that higher asphalt content increased wear in the long run, whereas penetration grade had little effect. Findings to the contrary have, however, been reported in Finland and Norway (5). The reasons for this may be in the masking effects of other properties in different mixes and in the test conditions, principally temperature, which has a considerable influence on wear rates (2, 6, 8). Different sources of asphalt cement and fine aggregate appear to have little independent effect on wear resistance (8). In addition to the properties for good wear resistance already mentioned, one or more of these European investigations have reported the following as being important: good adhesion of the asphalt cement to the stone (by using additives if necessary), resistance of the coarse aggregate particles to fracture, high stability of the matrix, and proper compaction with a close surface texture.

Some special types of bituminous mixtures, such as Gussasphalt (2, 7, 8, 9) and sand asphalt mixes, meeting the requirements of the British specification B. S. 594 (6, 7, 8, 9), appear to provide better wear resistance than the conventional ones, especially when surface treated with hard chippings (7, 8). Generally, wear resistance is increased with increasing stone or chip size up to at least ½ in. (8). The best wear resistance of all appears to be given by stone-filled sand asphalt mixes (B. S. 594) into which precoated hard chippings are hot-rolled. This type of stone-filled sand asphalt is similar to, in most respects, and is sometimes otherwise known as, Topeka mix.

Properly designed and laid surface treatments using hard chippings have shown good wear resistance comparable to that of hot-mix pavements until raveling occurs (6). However, slurry seals and thin bituminous overlays have worn very rapidly, probably due to the small grain size of the aggregate (6).

From these findings and those mentioned earlier in this report, it appears that the best known way, at present, of improving the wear resistance of bituminous pavements is to incorporate the maximum amount of the hardest available aggregate in the surface, both because it has superior wear resistance and because any form of surface treatment makes the best use of what may be quite expensive hard aggregates. Type B. S. 594 hot-rolled asphalt with precoated, hard, wear-resistant chippings is potentially very advantageous for both repair work and new construction.

The wear resistance of concrete pavements has been included in some European investigations (2, 9, 10), but the work has not been as extensive as that on bituminous pavements. Orbom (10) in Sweden found that increased coarse aggregate content, consolidation by vibration, and use of water-reducing admixtures all improved wear resistance, while he found no correlation between wear and cement content or the shape or petrographic properties of the coarse aggregate particles. However, all of the concretes he studied contained relatively hard aggregates. This may also account for the relatively good wear resistance of concrete pavements reported by Wehner (2) in Germany and Thurmann-Moe (9) in Norway. The latter, however, reported considerable variability that he attributed to nonuniformity during construction. The first year's performance on the Ontario trial sections of uniformly high quality pavement concrete, containing hard trap rock coarse aggregate, reported in the next section appears to confirm that, to improve resistance to stud wear, the maximum amount of the hardest available coarse aggregate should be used.

Experimental Wear-Resistant Concrete and Bituminous Surfaces and Traffic Markings

In order to evaluate some of the more promising wear-resistant surfaces that might be used in Ontario and to study the effects of stud wear on skid resistance, trial sections have been included in 2 recently built pavements. Limited experiments under road conditions have also been started to find more permanent lane marking systems. Information on performance is not yet available for the traffic markings, or the bituminous sections; and a trial concrete pavement has only been opened to traffic for one year. In spite of this, some features of these experiments may be worth brief mention.

Fourteen experimental concrete sections, each 250 ft long and 1 lane wide, were constructed in the fall of 1968. They are located in the westbound lanes of the MacDonald Cartier Freeway (Toronto Bypass) at Dixon Road and are thus subjected to similar heavy traffic as that at the test locations on this highway on which wear was reported earlier in the paper. In the test sections the normal fine aggregate was successively replaced up to 100 percent with a high silica sand with 3 types of coarse aggregate, dolomitic limestone, blast furnace slag, and trap rock. On special sections blends of coarse aggregate were tried or carborundum grit was incorporated in the surface during finishing.

TABLE 3

DETAILS OF TEST SECTIONS OF WEAR AND SKID-RESISTANT BITUMINOUS PAVEMENTS

Type of Mix	Mix No.	Stone Percent Weight of Aggregate	Filler Percent Weight of Aggregate	Fine Aggregate Percent Weight to Make 100 Percent Weight Aggregate	Asphalt Percent Weight of Mix
Mixes Placed					
HL1 with increasing stone contents	1	40 TR	–	LSS and local sand	5.6
	2	50 TR	–		5.2
	3	60 TR	–		4.9
TR and TRS only, no intermediate sand	4	40 TR	–	TRS	4.5
	5	50 TR	–		4.3
	6	60 TR	–		4.0
HL1 as above but with SS and TRS	7	40 TR	–	SS and TRS 1:2	4.8
	8	50 TR	–		4.3
	9	60 TR	–		4.3
As Mix 7, 8, and 9 but reversing the ratio of SS:TRS	10	40 TR	–	SS and TRS 2:1	6.2
	11	50 TR	–		5.3
	12	60 TR	–		4.7
HL1 using SS and filler	13	40 TR	Limestone 7	SS	5.5
	14	50 TR	4		5.2
	15	60 TR	2		4.7
Asbestos filler mixes	16	45 TR	Asbestos 2	TRS	7.0
	17	45 TR	2	TRS and sand 1:1	7.0
S ½ in. maximum size and regular fine aggregate	18	30 S	–	LSS and sand	7.0
	19	40 S	–		6.8
	20	50 S			6.5
As Mix 18, 19, and 20 with the addition of TRS	21	30 S	–	LSS and sand and TRS 2:1	6.4
	22	40 S	–		6.2
	23	50 S	–		6.2
Crusher run hard metallurgical slag mixes ⅜ in. (2 types)	24	Slag 1	–		6.5
	25	Slag 2	–		5.6
Carpet seal with reduced fines content	26	30 TR	–	70 TRS	6.0
Standard HL3 mix using limestone coarse aggregate for comparison of wear	27	40 LS	–	LSS and sand	6.0
Mixes Planned But Not Yet Placed					
Standard HL1 with surface treatment using precoated TR chips	28	40 TR	–	LSS and sand	5.6
Gussasphalt with rolled-in precoated TR chips	29	–	–		–
B. S. 594 stone mix and precoated TR	30	27	12	61	9.3
B. S. 594 stone mix and precoated S	31	27	12	61	9.3
B. S. 594 sand carpet and precoated TR	32	0	16	84	11.3

Note: Each section is approximately 300 ft long. Small areas of precoated chippings were tried with standard HL3 mix (trap-rock chips) and HL1 (Sinopal chips) to establish relative wear of chips, but not skid resistance. Abbreviations are TR = trap-rock, LS = limestone, TRS = trap-rock screenings, LSS = limestone screenings, S = Sinopal, and SS = silica sand.

After one winter's exposure to studded tire traffic, the high silica sand sections have worn as much as those containing the softer, normal sands, thus exposing the coarse aggregate to wear. The carborundum grit surface treatment was removed in a few days by traffic and must be regarded as completely ineffective. Those sections containing trap-rock have, however, displayed excellent wear resistance. As shown in Figure 6, the surrounding matrix has been removed by studs and the coarse aggregate particles now stand exposed and proud. One result of this is that the pavement, after one winter, gave the best skid resistance of any recorded on concrete in Ontario (skid numbers by ASTM trailer 52 at 30 mph, 37 at 60 mph). It remains to be seen whether these benefits are maintained or whether the aggregate particles become dislodged by traffic.

Outline details of the experimental sections of bituminous pavement are given in Table 3. The sections were laid in the late fall of 1969 on Highway 400 northbound driving lane, north of King Side Road some 25 miles from Toronto. These test sections are expected to receive similar exposure to studded tires as that at the test locations on the same highway whose wear was reported earlier. Certain sections including, unfortunately, the B.S. 594 hot-rolled asphalt could not be completed due to the onset of winter and problems with materials. It is intended to lay these in the spring of 1970.

Three different approaches have been tried to find more permanent types of traffic markings. Forty-thousand linear feet of broken centerline thermoplastic markings were laid on approximately 23 miles of existing bituminous and concrete pavements subjected to heavy traffic. On new construction, Sinopal, a hard, white, synthetic aggregate with excellent light reflectance, has been incorporated in the pavement surface where lane markings were required. On both new construction and existing pavements, longitudinal saw cuts about $^3/_8$ in. apart and $^1/_4$ in. deep have been made and the strips painted. By first grooving the pavement it is hoped to protect the paint in the cuts below road level and provide breaks in the water film to render the painted strips visible on wet nights.

Possible Remedial Measures

Table 4 gives some alternative repair methods, improved wear-resistant surfaces, and traffic markings together with their estimated cost per 2-lane mile. The costs are representative only and are based on work at prevailing prices in one area (Hamilton District) using currently available methods and equipment. A dominant influence on the costs is the haul distance for the hard coarse aggregate required. In the representative case used, this is about 200 miles (trap-rock from Havelock or Marmora). Doubling the haul would increase the surfacing costs quoted by about 15 percent.

Experiments are being made in Norway (9), Sweden (4), and probably elsewhere into economical and practical methods of repairing only the worn wheel tracks. However, until the technique and equipment for doing this are ready for every day use it appears that full width resurfacing and local patching will be used to repair damage to existing pavements.

IDENTIFICATION OF INCREASED COSTS

The 4 main sources of increased costs due to the continued use of studded tires appear to be the following:

1. The cost of using improved wear-resistant concrete and bituminous surfaces on new construction;
2. The cost of using improved wear-resistant materials in the normal resurfacing program;
3. The additional costs arising from the increase in the resurfacing program due to the use of studs, and extra patching where vehicles stop, start, or turn; and
4. The cost of more wear-resistant traffic markings for both existing pavements and new construction.

At this time it is not possible to accurately estimate the increased costs for each of these items for individual projects. However, to estimate additional costs, we can as-

TABLE 4

TYPES OF WEAR-RESISTING SURFACES AND TRAFFIC MARKINGS WITH ESTIMATED COSTS

Item	Description	Total Cost Per 2-Lane Mile ($)	Additional Cost Per 2-Lane Mile ($)
	Repair work—bituminous pavements		
1	Burning out and patching wheel tracks only with HL1	14,000	
2	Burning out and patching wheel tracks only with HL1 containing 20 percent additional trap-rock	14,800	
3	Burning out and patching wheel tracks only with sand asphalt followed by surface treating full width of pavement with hot precoated trap-rock chips	20,200	
4	Resurfacing full pavement width (including filling in wheel tracks) with 1¼ in. HL1	12,300	
5	Resurfacing full pavement width (including filling in wheel tracks) with 1¼ in. HL1 containing 20 percent additional trap-rock	12,800	
6	Resurfacing full pavement width (including filling in wheel tracks) with 1 in. sand asphalt (B. S. 594) with ½ in. hot precoated trap-rock chips rolled into surface	11,000	
	Repair work—concrete pavements (Items 4, 5, and 6 are applicable)		
	Existing pavements—traffic markings		
7	Thermoplastic or sawed and painted grooved lines	300	
	New construction—traffic markings		
8	Built-in Sinopal white lines	1,000	
	New construction—bituminous pavements		
9	Using HL1 containing 20 percent additional trap-rock in place of HL3 in surface courses		+2,400
10	Using 1 in. sand asphalt (B. S. 594) with ½ in. precoated trap-rock chips in place of HL1 surface courses		-800
11	Using 1 in. sand asphalt (B. S. 594) with ½ in. precoated trap-rock chips in place of HL3 surface courses		+500
12	Using HL3 in place of HL1 surface courses but surface treating with trap-rock chips		+4,600
	New construction—concrete pavements		
13	Using trap-rock coarse aggregate in the top 3 in. of pavement slab in place of local aggregates		+3,000

Note: Items 4, 5, and 6 would require raising of the shoulders (and possibly manholes, catch basins, curb, and gutter) at an additional cost to those shown for these items of approximately $1,000 per 2-lane mile. Estimates for items 1, 2, and 3 are based on the prevailing process for relatively small volumes of work. Development of suitable mechanical equipment to produce the high volume production that would be required in the future should result in a considerable reduction in these costs.

sign representative costs given in Table 4 and extend them against the planned construction and maintenance programs for future years and the amount of existing highways likely to become worn by studs.

Approach Used and Assumptions Made for Estimating Purposes

Many assumptions have been made in considering the economic implications of the wear caused by studded tires. These are as follows.

1. General pavement wear in northern Ontario is unlikely to be substantial because traffic volumes are low, pavements are snow-covered for a longer time, and the local aggregates used in pavements are mostly of hard igneous rock that provides a fairly wear-resistant surface. Therefore, except for traffic markings, only southern Ontario, south of Sudbury-North Bay but including Highway 17 to Sault Ste. Marie, is considered in this report.

2. Within southern Ontario all King's Highways, both existing and planned, on which the AADT is less than 2,000 vehicles, have been excluded. (King's Highways in Ontario are those under the direct jurisdiction of the provincial government. Other highways are in county, city, town, or township systems. Such highways are collectively referred to as municipal roads and streets, and their construction and maintenance is partly subsidized by the provincial government.) It is unlikely, on the basis of experience to date, that the general wear that will occur with low traffic volumes will be such as to require premature resurfacing or to warrant provision of improved wear-resistant surfaces for new construction. Isolated areas at stop signs, traffic lights, intersections and so steep grades may, however, require patching because of stud damage.

3. The traffic figures used are based on 1967 surveys, which are the latest available. No account is taken of any subsequent increase in traffic in classifying the various mileages of highways according to traffic volume, but a 5 percent per annum increase in traffic has been taken into account, together with the anticipated increase in the percentage of use of studded tires, in predicting future wear.

4. Certain assumptions, based on the measured and predicted wear reported earlier, must be made as to the life of existing pavements under different traffic intensities as follows:

a. Wear will be independent of the type of pavement surfacing over the long term.

b. General wear in the wheel tracks to a depth of 1 in. will establish the time at which a pavement requires resurfacing to restore safe operation and satisfactory cross drainage. This is taken as the average life-span for the pavement concerned.

c. All existing pavements are considered initially to be in a new and unworn condition. This assumption is obviously untrue, but it will be shown later that an adjustment can be made to take into account normal resurfacing work for pavements that are already near the end of their service lives for reasons of presently occurring deterioration with time and traffic rather than studded tire wear.

d. Local variations in traffic operating conditions and in the percentage of studs in use will probably mean that some pavements will have shorter life-spans than the average for the group, and others will have longer. Accordingly, it has been assumed that 25 percent of the pavements in each group will require resurfacing 1 year before the average and that 25 percent will require resurfacing 1 year after the average life-span year.

e. Under the stated percentage of studded tire use and traffic volumes the average life-span of present pavement surfaces will be as follows:

Winter	Percent of Passenger Vehicles With Studded Snow Tires	AADT 2-Lane 2-Way (thousands)	Average Life-Span (yr)
1969-70	35	2 to 6	8
1970-71	50	6 to 10	5
1971-72	60	10 and more	3

It is assumed that no increase in studded tire use will occur after 1971-72. The life-spans are generally between one-half and one-fourth of those that would normally be expected from pavements in Ontario.

5. The improved wear-resistant surfacings, which will be used for repair work and new construction, will achieve half the life that would be expected from present pavement surfaces not subjected to studded tire wear.

6. Detailed information on traffic volumes and future construction programs of the type used in making predictions for the King's Highway system is not available for municipal roads and streets. Accordingly, the municipal situation is treated separately and the predictions are derived by prorating the results developed for the King's Highways.

7. The use of more wear-resistant surfaces for new construction and for resurfacing and patching work will start as soon as possible in the 1970 construction season. A change from the present method of painted traffic markings to a more durable one will commence next year.

8. Estimates are carried through to fiscal year 1978-79 because the following year (1979-80) is the year in which the cycle of repair work might be expected to start over again (see assumption 5).

9. It is estimated from data given in Table 4 that the cost of resurfacing a worn pavement will be $13,000 per 2-lane mile (shouldering work included), the additional cost of providing improved wear-resistant bituminous pavements will be $2,000 per 2-lane mile, the additional cost of providing improved wear-resistant concrete pavements

will be $3,000 per 2-lane mile, the additional cost of more permanent traffic markings for existing pavements will be $300 per 2-lane mile, and the additional cost of more permanent traffic markings on new construction will be $1,000 per 2-lane mile.

10. In preparing the estimates of additional costs that follow in the next section of the report, we made a breakdown of the construction and maintenance programs and the mileage of highway involved in terms of traffic volume and the number of lanes of pavement for each district into which the provincial highway system is divided for administrative purposes. However, in this report only the summary totals for the whole system in southern Ontario are given for each item in terms of the 2-lane equivalent miles of highway involved.

ADDITIONAL COSTS OF PROVIDING IMPROVED WEAR RESISTANCE ON KING'S HIGHWAYS ONLY

Forecast of Added Costs on New Construction

The cost of providing improved wear-resistant surfaces for bituminous pavement, and for concrete pavement is given in Table 5. The additional cost is directly related to the volume of construction each year, and in only one year is it likely to exceed $0.75 million. This should be viewed in relation to a total cost of new construction each year, which may approach $200 million of which pavement costs are in the region of $20 million. It should not be overlooked that a secondary benefit of improved wear-resistant surfaces would be to generally improve skid resistance.

Table 5 also gives the additional costs of providing more permanent traffic markings on new construction. These costs are directly related to the volume of construction in any one year and are very preliminary because the success of the experimental markings described earlier and their cost for volume production are not yet known.

Forecast of Added Costs to the Normal Resurfacing Program

Table 5 (Item 3) gives the mileage of pavement scheduled for resurfacing to meet normal wear and tear. In the future it is assumed that this resurfacing, averaging about 200 miles per annum, should incorporate more wear-resistant materials. The additional cost of this in the peak year is $532,000.

In addition, about 120 equivalent 2-lane miles of pavement are patched in short sections each year at a cost of $1,450,000. The cost of this maintenance patching would be increased by $240,000 per year if more wear-resistant surfaces were provided. Again, as on new construction, this expenditure would also provide better skid resistance.

Forecast of Added Costs for Traffic Markings on Existing Highways

Painted traffic markings, particularly centerlines and stop lines at intersections, are being worn away by studded tires within a few weeks after the onset of winter. Because repainting is not possible until spring, longer lasting materials must be used in both northern and southern Ontario.

The present cost of centerline painting is approximately $30 per 2-lane mile of pavement for a total cost of about $600,000 per year on the King's Highway system. Thermoplastic markings last longer but cost between 10 and 15 times more than paint. If during a 3-year period it becomes necessary to convert all existing paint markings to thermoplastic, the additional cost, after deducting the cost of painting, is given in Table 5 (Item 4).

Because thermoplastic centerline markings do not receive the concentration of wear that occurs in the wheel tracks, their life is expected to be 5 years. Therefore, from 1975-76 onward these markings would require renewing, over a 3-year cycle, at $1 million per year.

The total cost of more permanent markings for existing pavements, 1970-71 to 1977-78, is $4.8 million.

TABLE 5

ESTIMATED ADDITIONAL COSTS OF IMPROVED WEAR-RESISTANT SURFACES AND TRAFFIC MARKINGS FOR NEW CONSTRUCTION AND MAINTENANCE WORK ON KING'S HIGHWAYS ONLY

Item	Year	Miles	Value	Additional Costs
1. New construction of bituminous pavements[a]	1970-71	226.4	8,297	453
	1971-72	283.1	11,072	566
	1972-73	280.8	10,506	562
	1973-74	219.6	7,874	439
	1974-75	250.0[b]	9,000[b]	500[b]
2. New construction of concrete pavements[c]	1970-71	51.7	5,687	155
	1971-72	19.6	2,156	59
	1972-73	97.6	10,736	293
	1973-74	81.9	9,009	246
	1974-75	75.0[d]	7,500[d]	225[d]
3. Normal resurfacing program[e] (not including mileages of resurfacing due to stud wear)	1970-71	174.5	6,305	349
	1971-72	224.0	7,622	448
	1972-73	265.9	9,051	532
	1973-74	174.5	5,815	349
	1974-75	200.0[f]	7,000[f]	400[f]
4. More permanent pavement traffic markings on existing roads[g]	1970-71	10,000	600	800
	1971-72	10,000	600	600
	1972-73	10,000	600	400
	1973-74	–	–	–
	1974-75	–	–	–
5. More permanent pavement traffic markings on new construction[h]	1970-71	278	–	278
	1971-72	302	–	302
	1972-73	378	–	378
	1973-74	302	–	302
	1974-75	325[i]	–	325[i]

[a]Miles = 2-lane miles; value = pavement costs only in thousands of dollars; and additional costs are in thousands of dollars and are based on $2,000 per 2-lane mile to provide improved wear-resistant surfaces.

[b]Full extent of new construction for bituminous pavements is not yet programmed. In the estimation of overall costs from 1974-75 onward, it is assumed that the construction program will continue at about 250 miles per year. Thus for the years 1975-76, 1976-77, 1977-78, and 1978-79, the relevant figures are 250 for miles, $9 million for value, and $500,000 for additional costs.

[c]Miles = 2-lane miles; value = pavement costs only in thousands of dollars; and additional costs are in thousands of dollars and are based on $3,000 per 2-lane mile to provide improved wear-resistant surfaces.

[d]Full extent of new construction for concrete pavements is not yet programmed. In the estimation of overall costs from 1974-75 onward, it is assumed that the construction program will continue at about 75 miles per year. Thus for the years 1975-76, 1976-77, 1977-78, and 1978-79, the relevant figures are 75 for miles, $7.5 million for value, and $225,000 for additional costs.

[e]Miles = 2-lane miles; value = pavement costs only in thousands of dollars; additional costs are in thousands of dollars and are based on $2,000 per 2-lane mile to provide improved wear-resistant surfaces; and $240,000 per year in addition to that shown added in final estimate to cover additional cost of improved wear-resistant surfaces in maintenance patching work.

[f]Full extent of normal resurfacing is not yet programmed. In the estimation of overall costs from 1974-75 onward, it is assumed that the resurfacing program will continue at about 200 miles per year. Thus for the years 1975-76, 1976-77, 1977-78, and 1978-79, the relevant figures are 200 for miles, $7 million for value, and $400,000 for additional costs.

[g]Total mileage-lane marking; value = $30 per mile, painted twice per year, in thousands of dollars; additional costs are in thousands of dollars and are based on conversion to more lasting marking during 3-year period at 10 times the value of existing system (deduction made for proportion of painted markings no longer required each year); and renewal of markings starts 1975-76 and continues over subsequent 2 years at annual cost of $1 million.

[h]Total miles of new construction of bituminous and concrete as in Items 1 and 2; no value attached to traffic markings that will not now be required; and additional costs are in thousands of dollars and are based on miles of new construction each year times $1,000 per mile.

[i]Full extent of new construction is not yet programmed. In estimation of overall costs from 1974-75 onward, it is assumed that construction program will continue at about 325 miles per year. Thus for 1975-76, 1976-77, 1977-78, and 1978-79, the relevant figures are 325 for miles, $1,000 for value, and $325,000 for additional costs.

ADDITIONAL COSTS OF RESURFACING AND PATCHING WORK ARISING EXCLUSIVELY FROM STUDDED TIRE WEAR ON KING'S HIGHWAYS ONLY

Amount of Existing Pavement Susceptible to Premature Wear

The King's Highway system contains 10,000 route miles of pavement. Of this mileage, 4,236 miles in southern Ontario have traffic volumes greater than 2,000 AADT and are considered susceptible to premature wear by the continued use of studded tires. A breakdown of this mileage in terms of equivalent 2-lane miles for each of the 3 levels of traffic volume considered in this report is as follows:

AADT (thousands)	Average Life-Span	2-Lane Miles
2 to 6	8	3,087
6 to 10	5	1,141
10 and more	3	997

Estimate of the Cost of Repairs Made Necessary by Stud Wear

Table 6 (Item 1) gives a forecast of the cost of repairs necessitated by stud wear on the mileages of pavements shown in the preceding tabulation for each year through to the 1978 construction season. This is the time at which the last 25 percent of the group with the lowest traffic volume will be worn to the point where resurfacing will be necessary. None of the more heavily traveled pavements that have been resurfaced in earlier years nor any of the new pavements built with improved wear-resistant surfaces should yet require repair. It must be expected, however, that some of these at 6 or 7 years of age will need repair the following year, thus recommencing the cycle in 1979-80.

Costs increase rapidly in later years, when a large mileage of the more lightly traveled pavements are expected to become worn, to a peak of $20 million in 1977-78. Though additional costs are lower in the earlier years, much of the work is on heavily traveled roads, such as the Toronto Bypass, and includes pavement which, at the time of writing, is newly laid.

Forecast of the Added Cost Due to Stud Wear

Table 5 (Item 3) gives the normal resurfacing program, both capital and ordinary, through to 1973-74 with projections for the following 5 years for highways in southern Ontario with AADT greater than 2,000. Total costs and the additional cost of providing an improved wear-resistant surface are given.

The mileage of this resurfacing is that which would be required for normal reasons (such as deterioration due to normal traffic), but it naturally includes many of the same

TABLE 6

ESTIMATED TOTAL COSTS OF RESURFACING DUE TO STUDDED TIRE WEAR ON EXISTING PAVEMENTS OF KING'S HIGHWAYS ONLY

Item	Year	Amount	I[a]	II[b]	Difference[c]
1. Estimated cost of resurfacing pavements worn by studded tires x $1,000[d] (no allowance made for resurfacing required for other reasons)	1970-71	0			
	1971-72	3,237			
	1972-73	6,482			
	1973-74	6,951			
	1974-75	7,420			
	1975-76	3,710			
	1976-77	10,029			
	1977-78	20,067			
	1978-79	10,038			
2. Additional costs of resurfacing pavements due to wear by studded tires[e] (allowance made for resurfacing required by normal deterioration)	1970-71		2,268	0	0
	1971-72		2,912	3,237	+325
	1972-73		3,456	6,482	+3,026
	1973-74		2,271	6,951	+4,680
	1974-75		2,600	7,420	+4,820
	1975-76[f]		2,600	3,710	+1,110
	1976-77[f]		2,600	10,029	7,429
	1977-78[f]		2,600	20,067	17,467
	1978-79[f]		2,600	10,038	7,438

[a]Estimated cost of surface course for mileage of pavement given in Table 5 (Item 3) programmed for resurfacing due to normal wear (2-lane equivalent mileage x 13) in thousands of dollars.

[b]Estimated cost of surface course for mileage of pavement having traffic volumes greater than 2,000 AADT, as tabulated earlier, requiring resurfacing due to studded tire wear (2-lane equivalent mileage x 13) in thousands of dollars.

[c]Estimated additional costs where shown plus cost of resurfacing for studded tire wear over and above resurfacing programmed for other reasons.

[d]Expenditures for each of the 3 pavement groups having AADT greater than 2,000, as tabulated earlier, are distributed 25, 50, and 25 percent about the financial year corresponding to average life-span.

[e]Contingency item of $500,000 per year added for local patching required by studded tire wear at locations where vehicles stop, start, or turn, but where full resurfacing of highway is not required.

[f]Estimated costs of resurfacing program based on continuance of program at about the level of preceding years.

pavements that would be prematurely worn out by studs. The true additional cost of work required because of the continued use of studded tires must be found by difference as given in Table 6 (Item 2).

The values in Table 6 (Item 2) have been derived from Table 6 (Item 1) and Table 5 (Item 3). They are approximate because there is no certainty that "normal" wearing out of a pavement will coincide with the accelerated wearing out due to studded tires. Three factors, however, tend to increase the accuracy of this forecast:

1. In the first 2 or 3 fiscal years, "normal" resurfacing predominates, except on heavily traveled roads in one area;
2. Toward the end of the period, little normal resurfacing is, as yet, specifically scheduled, and the need to resurface highways worn by studs can be taken into account as one factor in deciding on the program; and
3. Over the middle of the period, adjustments will be possible in the resurfacing program as the extent and location of the worn pavements become apparent, so that, wherever possible, resurfacing of pavements to overcome both "normal" deficiencies and studded tire wear can be undertaken at the same time.

Total Additional Costs of Resurfacing and Patching Work

To arrive at the overall estimated additional costs of resurfacing and patching required because of studded tire wear, we have included the following items in Table 7:

1. The cost of the additional resurfacing due to studded tire wear over and above the normal resurfacing program (i.e., Table 6, Item 2);
2. The cost of providing improved wear-resistant surfaces for the normal resurfacing program (Table 5, Item 3);
3. The patching costs on a contingency basis of local areas where vehicles stop, start, or turn but where general resurfacing of the highway is not necessary (this cannot be accurately estimated; however, it is expected to be substantial, and $500,000 per year has been included from 1971-72 onward); and
4. The cost of providing improved wear-resistant surfaces in maintenance patching each year ($240,000 per year).

ADDITIONAL COSTS ON MUNICIPAL ROADS AND STREETS

Because of the lack of data on municipal roads and streets in Ontario, only a broad estimate of the added costs resulting from the continued use of studded tires can be made on the basis of prorating the additional costs to either overall expenditures on

TABLE 7

ESTIMATE OF ADDITIONAL COSTS OF DEPARTMENT AND MUNICIPAL NEW CONSTRUCTION AND MAINTENANCE WORK DUE TO THE CONTINUED USE OF STUDDED TIRES

Financial Year	Department of Highways				Municipalities				Grand Total
	New Pavement Construction[a]	Resurfacing and Patching[b]	Traffic Marking[c]	Total	New Pavement Construction[d]	Resurfacing and Patching[e]	Traffic Marking[f]	Total	
1970-71	608,000	589,000	1,078,000	2,275,000	458,000	470,000	1,078,000	2,006,000	4,281,000
1971-72	625,000	1,533,000	902,000	3,060,000	469,000	1,226,000	902,000	2,597,000	5,657,000
1972-73	855,000	4,298,000	778,000	5,931,000	641,000	3,438,000	778,000	4,857,000	10,788,000
1973-74	683,000	5,769,000	302,000	6,754,000	512,000	4,615,000	302,000	5,429,000	12,183,000
1974-75	625,000[g]	5,960,000[g]	325,000[g]	6,910,000	469,000	4,768,000	325,000	5,562,000	12,472,000
1975-76	625,000[g]	2,250,000[g]	1,325,000[g]	4,200,000	469,000	1,800,000	1,325,000	3,594,000	7,794,000
1976-77	625,000[g]	8,569,000[g]	1,325,000[g]	10,519,000	469,000	6,855,000	1,325,000	8,649,000	19,168,000
1977-78	625,000[g]	18,607,000[g]	1,325,000[g]	20,557,000	469,000	14,886,000	1,325,000	16,680,000	37,237,000
1978-79	625,000[g]	8,578,000[g]	325,000[g]	9,528,000	469,000	6,860,000	325,000	7,654,000	17,182,000
Total	5,896,000	56,153,000	7,685,000	69,734,000	4,425,000	44,918,000	7,685,000	57,028,000	126,762,000

[a] Costs taken from Table 5 (Items 1 and 2) include both concrete and bituminous pavements.
[b] Costs taken from "Difference" column in Table 6 (Item 2) plus additional costs of providing more wear-resistant surfaces for the normal resurfacing program (Table 5, Item 3).
[c] Additional cost of providing more permanent traffic markings for both new pavements and existing ones (Table 5, Items 4 and 5).
[d] Taken as 75 percent of corresponding King's Highway figures.
[e] Taken as 80 percent of corresponding King's Highway figures.
[f] Taken as 100 percent of corresponding King's Highway figures.
[g] Estimated figure based on continuance of department's construction and resurfacing program at about the level of preceding years.

new construction or the mileage of existing pavement likely to need resurfacing. The additional costs resulting from the items below are given in Table 7 by fiscal year.

Forecast of Added Costs on New Construction

The capital expenditure on new road construction by the municipalities and the Department of Highways in 1967-68 was as follows:

Facility	Expenditure (millions of dollars)
King's Highways	159
County roads	47[a]
City and town streets	40
Metro roads	31

[a]Includes development roads.

Township roads are disregarded because few, if any, of these roads will carry heavy traffic volumes and require improved wear-resistant surfaces. The expenditure by municipalities on new construction is, therefore, about 75 percent of that spent on the King's Highways. It is assumed that their added costs will be in the same proportion, and for estimating purposes a figure of 75 percent of the increased costs to the Department of Highways in any year has been used.

Forecast of Added Costs for Resurfacing and Patching Work

The comparative mileages of existing pavement (1968) are as follows:

Facility	Total Mileage	Miles of Concrete Pavement	Miles of High-Class Bituminous Pavement	Route-Miles Carrying More Than 2,000 AADT in 1967
King's Highways	10,001.5	394.8	7,987.7	4,236.0
County roads	9,319.0	39.7	3,140.3	1,000.0
City and town streets	11,728.0	539.0	4,753.7	2,400.0
Metro roads	369.7	21.2	341.4	350.0

Townships have been disregarded because few, if any, of their roads were carrying high traffic volumes. It is estimated, therefore, that about 3,750 miles of municipal roads with AADT of over 2,000 are likely to be affected by premature wear due to studded tires, compared to 4,236.0 miles of King's Highways. The municipal mileage is 89 percent of the provincial highway mileage that will be similarly affected. It is assumed, therefore, that additional costs of resurfacing and patching work to municipalities will be 90 percent of those occurring to the province in any year.

Forecast of Added Costs for Traffic Marking

Finally, because of the greater amount of traffic marking generally required on municipal roads in urban areas to indicate stop streets, pedestrian crossings, and the like, 100 percent of the corresponding department's figure has been used in preparing the estimate.

OVERALL ESTIMATE OF ADDITIONAL COSTS

Table 7 gives a summary of the additional cost for both department and municipal work that may be expected to arise from the continued and increased use of studded tires in Ontario.

The costs involved are considerable, quickly rising in the early 1970's to over $6 million per year on the King's Highways where the more heavily traveled roads will require resurfacing and reaching peak figures of $10 and $20 million in 1976-77 and 1977-78, reflecting the very large mileage of the more lightly traveled roads, which will by then have become worn to a point requiring repair. Costs of providing traffic markings will show an immediate increase next year if more permanent marking materials are brought into use on existing pavements, and a peak of over $1 million per year will be reached in the mid-1970's when these markings will need replacement. The increased costs for new construction will remain relatively stable unless the program of work is increased or reduced in future years. The costs for municipal work reflect similar trends because they are prorated from those for the King's Highway system.

Total additional costs amount to close to $127 million during the next 9 years. Neglecting any increase in the present budget or decline in the value of the dollar, the cost of studded tire wear could amount to about 3 percent of the total expenditure on highways in the province of Ontario during this period.

By the winter of 1971-72 the number of cars registered in Ontario and fitted with studs may exceed 1,500,000 if no action is taken to restrict the use of studded tires. The estimated additional costs due to studs in the following financial year is just over $10,750,000; this amounts to about $7 per car per year.

The estimates outlined here are, of necessity, very approximate, but they indicate the general order of the additional costs that will arise during the next few years if the use of studded tires is allowed to increase freely.

CONCLUSIONS

The use of studded tires on about 15 to 20 percent of passenger vehicles in Ontario caused significant pavement wear on both concrete and bituminous pavements during 1 winter.

The rate of wear and type of wear are related to characteristics of the pavement surface. Of these, the hardness of the coarse aggregate appears to be the most significant.

The rate of wear is directly related to the volume of traffic and the percentage of vehicles with studs; significant wear may be expected with time even where traffic volumes are as low as 2,000 AADT.

The wear is concentrated in the wheel tracks on the open highway and elsewhere at locations where vehicles stop, start, or turn. Painted traffic markings are worn away within a few weeks.

Projections of present wear into future wear indicate that the problems will assume serious proportions within the next 2 to 3 years if the use of studded tires continues and increases at the anticipated rate of 60 percent within this period. One inch of wear in the wheel tracks (which because of its likely effect on pavement drainage and the safe operation of vehicles has been arbitrarily selected as the criterion for resurfacing worn pavements) is likely by that time on heavily trafficked roads. Subsequently, roads carrying lower traffic volumes will be progressively affected by wear.

It is indicated that improved wear resistance in both concrete and bituminous pavements is most easily and cheaply obtained by incorporating the greatest possible amount of the hardest available aggregate in the immediate pavement surface.

Restoring pavements worn by studded tires will require either use of conventional resurfacing and patching methods or use of newly developed repair techniques on a large scale. At present resurfacing of the full pavement width by using improved wear-resistant surfacing materials appears to be the only known and satisfactory method of remedying general wheel track wear.

If the use of studded tires continues and increases, widespread resurfacing and additional patching will be required at considerable cost. Estimates developed for 4,236 route miles of King's Highways and 3,750 miles of municipal roads and streets in southern Ontario that are likely to be affected place these additional costs at $100 million spread over the next 9 years.

It is unlikely that any measures that can be taken to improve the wear resistance of pavement surfaces will give them a life under studded tire use equivalent to that provided by present surfaces not subject to stud wear. Resurfacing is, therefore, likely to need repeating at frequent intervals.

The introduction of improved wear-resistant surfaces and traffic markings on new construction to delay the need for resurfacing because of wear will increase pavement construction costs in the order of 5 percent, which may not be intolerable when the secondary benefits of the improved safety provided by the better skid resistance of the pavements and visibility of traffic markings are taken into account. Total additional costs for these items for highways in southern Ontario is estimated at $27 million spread over the next 9 years.

Against the additional costs due to wear, estimated at $127 million during the next 9 years, any benefits, as outlined elsewhere (3), of studded tires as an aid to winter driving must be offset.

Research and development work is urgently required into the following aspects of the studded tire problem: (a) other repair methods than full width resurfacing; (b) the development of wear-resistant pavement surfaces; (c) the development of more permanent pavement traffic marking systems; and (d) alternative traction and directional control aids for vehicles operating under winter conditions, that, unlike tire studs or chains, do not damage pavement surfaces. In relation to the whole problem of safe and convenient operation of vehicles on the highway in winter, the last of these items is of most potential benefit.

REFERENCES

1. Questionnaire Survey by Minnesota Department of Highways. Answers reported to participants by a private communication, May 1969.
2. Wehner, B. Beanspruchung der Strassenoberflaeche durch Winterreifen mit Spikes. Technische Universitaet Berlin, Institute fur Strassen und Verehrsivesen. 1966.
3. Rosenthal, P., Haselton, F. R., Bird, K. D., and Joseph, P. J. Evaluation of Studded Tires: Performance Data and Pavement Wear Measurement. NCHRP Rept. 61, 1969.
4. Keyser, J. H. Effect of Studded Tires on the Durability of Road Surfacing. Presented at the 49th Annual Meeting and published in this Record.
5. Rosengren, A. An Investigation Concerning Studded Tires, With Special Reference to Pavement Wear, Based on Literature Studies. The National Swedish Road Research Institute, Stockholm, Spec. Rept. 81A, 1969.
6. Hultala, Matti. The Wearing Effects of Studded Tires on Certain Asphalt Pavements. The State Institute for Technical Research, Helsinki, Finland, 1967. (English summary provided.)
7. Anderson, O., Lilja, B., Rosengren A., Astrom T., and Orbom, B. Pavement Wear Due to Studded Tires Measured on the Test Road Machine of the National Swedish Road Research Institute. The National Swedish Road Research Institute, Stockholm, Spec. Rept. 83A, 1969.
8. Peffekoven, W. Laboratory Investigations of the Abrasion of Asphalt Pavements Under Studded Tires. Shell Research, N. V. Amsterdam, unpublished, 1969.
9. Thurmann-Moe, T. Pavement Wear Caused by Studded Tires. Norwegian State Highway Laboratory, Oslo, 1969.
10. Orbom, B. The Effect on Concrete Pavement of Studded Winter Tires. First European Symposium on Concrete Pavements, Paris, 1969.

Appendix

DESCRIPTION OF PAVEMENT SURFACES REFERRED TO IN THE REPORT

In the text, tables and figures of the report, various types of pavement surfaces in use in Ontario and elsewhere are referred to. The following identifies these surfaces and briefly describes their salient characteristics.

CONCRETE

Portland cement concrete containing 569 lbs. of Type I cement and about 50 percent coarse aggregate (by weight of total batch), nominal maximum size 1½ in., Slump 1½ in. to 2 in., Air Content 4½ to 6 percent. Pavement surface finished with a long wheel based transverse float and cured with wet burlap, plastic sheet or white pigmented membrane, the last of these being the most common on recently constructed pavement. Pavements constructed between 1961 and 1968 received an application of linseed oil. Those constructed before and after these dates did not. Longitudinal burlap drag texturing applied prior to the Fall, 1968; pavements subsequently constructed received a transverse broom finish.

BITUMINOUS

Three types of hot-laid bituminous concrete surface courses are in general use in Ontario. All are laid and compacted by conventional means.

H.L.1.

Used on major heavily trafficked highways only. Contains 40 to 50 percent quarried trap-rock coarse aggregate (by weight of the total aggregate fraction) 100 percent passing ½ in. graded down to 3/16 in. Asphalt content 5 to 7 percent usually 85-100 penetration grade in the south and central part of southern Ontario and 150-200 penetration grade in the north and eastern parts. Local sand used as fine aggregate which may be augmented by quarried screenings to correct grading deficiencies. Mineral filler only used on rare occasions.

H.L.3.

Used on highways with moderate traffic. Mix characteristics similar to H.L. 1. except that the coarse aggregate is a crushed material from commercially operated gravel pits or quarries. Many of these sources in Southern Ontario contain relatively soft sedimentary materials.

H.L.4.

Used on highways with moderate to light traffic. Designed to make use of as many local roadside sandy gravel pits as possible. Maximum size of coarse aggregate fraction 5/8 in. with wide grading tolerance that permits stone contents between 33 and 60 percent. Asphalt content 4.5 to 7 percent, same grades as H.L.1. In central and northern Ontario the parent aggregate rock is usually hard igneous, in the more southerly parts softer materials predominate.

B.S 594 Hot-Rolled Asphalt

Widely used on roads with heavy traffic in Britain. Essentially a sand-asphalt mix which may be stone filled. Stone content may range from 0 to 55 percent. Examples of typical mixes are:

PERCENTAGE BY WEIGHT OF TOTAL MIX (B.S 594 1960)				
	STONE RETAINED U.S. NO. 8	ASPHALT CEMENT*	FILLER PASS NO. 200	SAND
Sand Carpet	0	11.3	14.0	74.7
Stone Filled	25 (all passing ½ in.)	9.3	11.0	55.7

* *Asphalt-cement usually 50-60 penetration grade but 85-100 sometimes used.*

	U.S. SIEVE SIZES	NO. 8	NO. 30	NO. 70	NO. 200
Sand Grading	Percent Passing by Weight	95-100	50-100	5-58	0-3

Where the stone content is less than 45 percent pre-coated hot aggregate chippings are usually spread on the surface of the pavement mat immediately behind the initial roller and are then rolled in flush with the surface during final compaction. Chippings, usually of a superior stone having good wear and skid resistant properties are pre-coated hot with asphalt cement and mineral filler and then stockpiled prior to use. Depending on the size of chipping two spreading rates are used - ¾ in. - 70 to 130 sq.yds./ton, ½ in. 100 to 160 sq.yds./ton. Uniform distribution is extremely important.

Topeka Mixes

A stone filled sheet-asphalt in more common use many years ago as a wearing course. Usually contained about 25 percent coarse aggregate all passing ½ in. graded down in a typical example to 11 percent passing No. 200, asphalt content 9 - 10 percent and would correspond almost exactly to a B.S 594 stone filled sand-asphalt mix of the same stone content.

Gussasphalt

An asphalt mastic surface course used mainly in West Germany composed of filler, ordinary asphalt and Trinidad Lake Asphalt, heated and mixed together for a period of several hours.