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ARIZONA'S PAVEMENT MANAGEMENT SYSTEM SUMMARY AND DEVELOPMENT OF ARIZONA'S OPERATIONAL PAVEMENT MANAGEMENT SYSTEM

(Non-Technical)

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ARIZONA'S

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16. Abstract

Report details the development of Arizona's presently operational pavement management system in a non-technical manner. Background material was drawn from Arizona's eight previous technical research reports spanning seven years. In addition, practical benefits, application and problems which occurred since implementation one year ago are discussed.

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ARIZONA'S PAVEMENT MANAGEMENT SYSTEM

INTRODUCTION

The Arizona Department of Transportation (ADOT) pavement management system (PMS) began in 1969 with the purchase of a Dynaflect. A series of reports documents the growth of PMS in Arizona.

(1) "Pavement Evaluation in Arizona", Allen, G.J., Cornell, C.S., Burns, J.C., Eisenberg, J.F., 11th Annual Paving Conference at the Univ. of New Mexico, Jan. 1974.

(2) "Development of Framework For Pavement Management System for Arizona", Woodward-Clyde & Consultants, Finn, F.N., Kulkarni, R., McMorran, J., Dec. 1976.

(3) "Arizona Pavement Management Systems - Pavement Monitoring Summary," Way, G.B.

(4) "Decision Criteria For the Arizona DOT Pavement Management System (PMIS)," Eisenberg, J.F., Pavement Management Workshop, Tumwater, Washington, Nov., 1977.

(5) "Implementation of ADOT's Pavement Management System (PMS)," Overview, Way, G.B., Arizona Conference of Roads and Streets, Univ. of Arizona, April 18, 1979.

(6) "Development of a Network Optimization System," Volume I & II, Woodward-Clyde Consultants, Kulkarni, R., Golabi, K., Finn, F., Alviti, E. and Nazareth, L., May 1980.

(7) "Verification of Performance Prediction Models and Development Of Data Base," Way, G.B. and Eisenberg, J.F., ADOT, Sept. 1980.

(8) "Analysis of Testing Frequency for Pavement Evaluation", Way, G.B., Eisenberg, J.F. and Delton, J.P, ADOT, Sept. 1981.

These eight reports constitute a body of knowledge which technically describes ADOT's system. Graphically the input portion of the system ultimately would look like Figure I. Systematic data collection and storage in an appropriate data base constitutes one of the most important portions of any PMS. Figure 2 portrays typical output reports including both a network and project optimization process. The combination of these components and coordinated operation constitutes a functional PMS which provides a set of powerful new tools to aid the decision maker.

In order to use these tools effectively it is important to understand them and how they work. The following text represents an attempt to convey the meaning of ADOT's PMS. Detailed information is contained in the eight reports. This historical summary is written from the standpoint of an interview, in which you the reader are asking the questions and we the authors are trying to answer.

What is a Pavement Management System?

A pavement mangement system (PMS) has been defined as "the systematic development of information and procedures necessary in optimizing the design and maintenance of pavements".

Well what the heck does that mean?

It means that highway managers have been faced with making decisions as to how to best spend the limited available funds to preserve the highway network. These decisions have been subjective out of necessity. A PMS will use objective measurements and mathematical functions to derive a suggested policy for preserving the highway condition.

Okay, but why do we need a PMS?

As the interstate system in Arizona has neared completion, the emphasis of highway engineers and managers has shifted from new construction to preserving the existing highway network. At present, ADOT has over 7,000 miles of highways within its system. The cumulative cost to construct the present system was about $2.1 billion. To replace the existing highways at today's dollars would amount to $4.0 billion; however, to overlay the entire system would cost about $500 million. The idea behind PMS is that it is possible through a systematic management methodology to extend the life of ADOT's highways at or above an acceptable level at a reduced cost.

Are other states also working on a PMS?

Yes, at the PMS workshop held at Tumwater, Washington in November, 1977 several states and provinces presented their state of the art in development of their PMS.

Arizona	New York	Texas
California	Ontario	Utah
Florida	Pennsylvania	Washington
Kentucky	Saskatchewan	

How does Arizona compare to these other states?

We believe ADOT has developed one of the best systems since ours comes closest to possessing all recommended working parts necessary for a totally functional system.

What are these parts?

At the 1980 Transportation Research Board a symposium on PMS was held. Arizona was a participant in this symposium. During the proceedings various speakers outlined those features necessary for a good PMS. These features included:

1. Adequate and reliable condition data, composed of past and present condition measurements such as rideability, cracking and slipperiness.
2. Prediction models capable of forecasting future pavement conditions.
3. A systematic method to determine what to do to each mile of highway and when to do it, in order to achieve the best possible future pavement performance.

   A design procedure capable of determining what type of action should be taken at each mile (overlay, overlay with special treatment, recycle etc). Also the thickness of the overlay or recycling layer or layers.

FIGURE I

PMS PROCESS

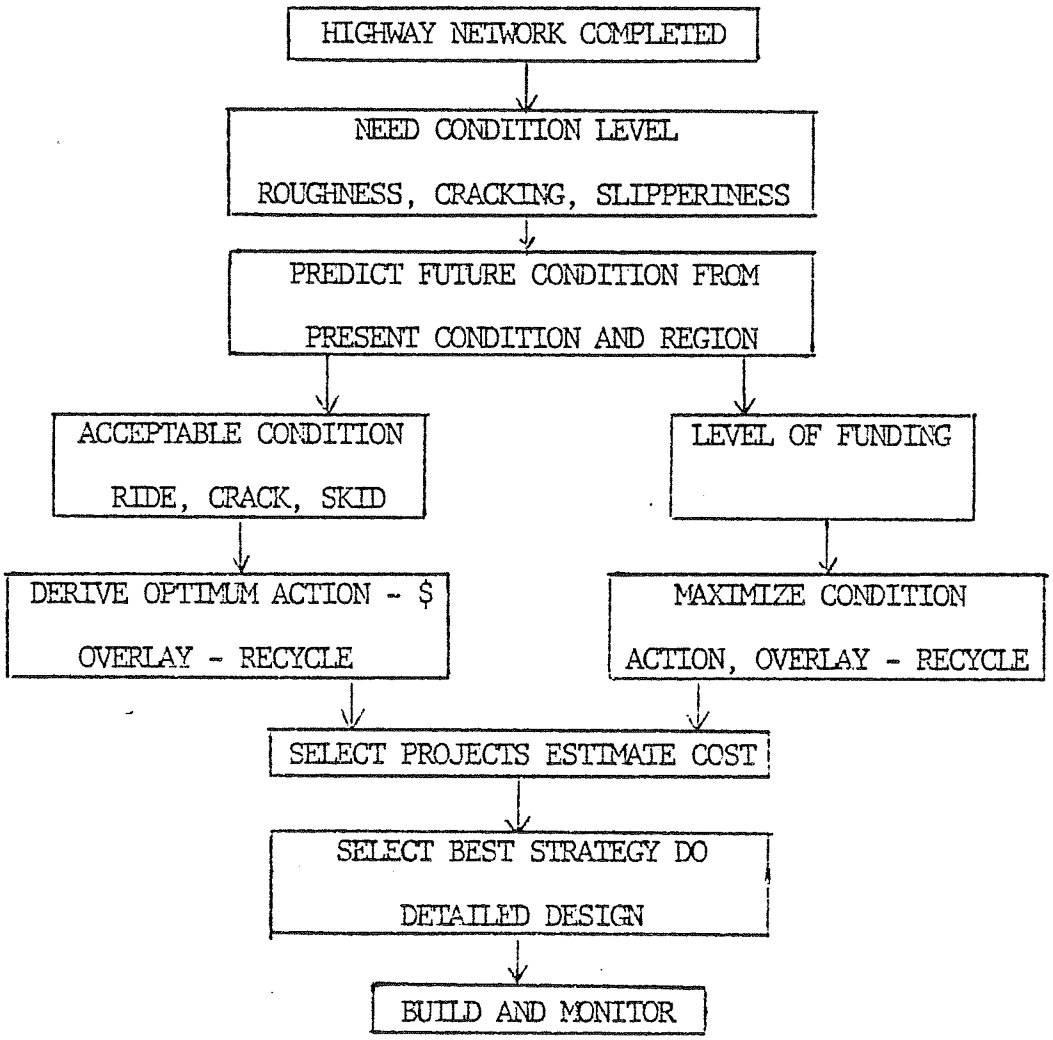


FIGURE 2

NOS ILLUSTRATION

ROUTE 31

	YEARS					
	ONE		TWO		THREE	
MILE	ACTION	COST	ACTION	COST	ACTION	COST
10	OVERLAY	45,000	MAINT	100	MAINT	150
11	OVERLAY	45,000	MAINT	100	MAINT	150
12	SEAL COAT	10,000	MAINT	250	MAINT	300
13	SEAL COAT	10,000	MAINT	250	MAINT	300
14	MAINT	750	MAINT	1000	OVERLAY	50,000
15	MAINT	600	MAINT	950	OVERLAY	50,000

FIGURE 2

SOMSAC ILLUSTRATION

PROJECT S 101(3) A

LENGTH 10 MILES - 20 YEAR LIFE

UTILITY (WORTH)	YEAR	ACTION	COST
.9630	0	OVERLAY	450,000
	9	OVERLAY	450,000
.9500	0	OVERLAY	450,000
	6	SEAL COAT	100,000
	9	SEAL COAT	100,000
	12	OVERLAY	300,000
.9100	0	OVERLAY	900,000
	12	SEAL COAT	100,000

4. Monitoring of construction, pavement performance and maintenance activities.

5. A data base capable of containing monitored information and efficient enough to allow rapid retrieval.

6. Sufficient cooperation and communication between all areas of the department, thus insuring rapid implementation and understanding of findings derived from examining the data base.

<u>You mean ADOT's system can do all these things. That seems like quite a lot, perhaps you could explain what each one means a little bit more. Lets start with number 1, what is our data base composed of at present?</u>

The data base contains each route number and mile of highway within the ADOT system. Divided highways are entered for both direction. For each mile several types of data are stored in the computer. This includes condition measurements for cracking, roughness, slipperiness and deflection. This data is stored by year. Historical and design data such as when construction was performed at a milepost, type of construction and thickness of layers are stored for each mile when they occurred. Likewise design data such as soil support, traffic (ADT, ADL) and regional factor are stored when they become available. At present the data base contains over 350,000 records and is expanding annually.

<u>This data base is large, isn't this a difficult thing to manage?</u>

Fortunately considerable work has gone into designing the data base so that it can be managed. Through a cooperative effort between Research, Materials and Information Systems it was possible to design and assemble the present data base. A period of five months were spent in the design and another six months in the initial assembly. The data base exists today, is workable and is being used.

That sounds pretty good but what about number 2, what are these prediction models?

Prediction models are equations which predict the future ride or cracking from the given conditions. By examining sample data from the data base it was possible through regression analysis to develop prediction equations.

What is regression analysis?

Regression analysis is a mathematical technique used to derive an equation by which the value of one variable can be estimated when the values of other variables are known. Since the present ride or cracking is known equations were derived to predict the change in ride or cracking in the next year. This value when added to the present value gives next years ride or cracking. At this point a new change in ride representing the second year can be predicted, thus future ride or cracking conditions can be predicted for as many years as desired. This type of equation where the last calculated value is used to calculate the next value is called a recursive, iterative or autocorrelation equation.

<u>What variables were tried and which ones constitute the final prediction equations?</u>

Variables included traffic (ADL), age, regional factor, deflection (all five deflections measured with the dynaflect), thickness of the asphaltic concrete (AC) and AC overlay as well as last years ride or cracking. The final equations for new construction or existing construction contain the following:

Change in Ride = FUNCTION OF [PRESENT RIDE, REGION]

Change in Cracking = FUNCTION OF [PRESENT CRACKING, CHANGE IN LAST YEARS CRACKING, REGION]

For Overlays

Change in Ride = FUNCTION OF [PRESENT RIDE, REGION]

Change in Cracking = FUNCTION OF [PRESENT CRACKING, CHANGE IN LAST YEARS CRACKING, REGION, INDEX OF TIME TO FIRST CRACK]

<u>This doesn't sound right. What happened to traffic, thickness and deflection, aren't they important? Shouldn't the final equation contain these terms?</u>

The models developed represent prediction of future roughness and percent cracking conditions based upon past experience. These models are intended to be used in conjunction with annual pavement condition surveys. These models <u>are not design equations</u> because they do not give any insight into what caused the distressed condition. Rather they represent a <u>what</u> system given what has happened they predict what will happen. Design equations try to represent why particular failures occur and develop design strategies to prevent or delay such occurrence. Even though traditional variables do not appear in these equations for the network problem, they probably should appear in the design equations. It is believed that both methods should predict expected performance reasonably well. For new construction ADOT may continue to use AASHTO design or some mechanistic design. In any case, the design equation predicting future performance should agree reasonably well with the network model equation in terms of predicted future condition.

<u>I'm not so sure I agree with all of that, what about overloads or changes in traffic volume, how does the system handle this?</u>

Changes in traffic volume in terms of ADT could place a mile of highway in a different traffic category where fixups are performed more often, however, it would not change the prediction equation. Traffic loading changes would be reflected in the project design. A subsystem that ADOT would eventually like to add would tie together loading, materials properties, deflection and thickness into a mechanistic or structural basis. At present traffic data is collected and special studies outside of the system can be performed.

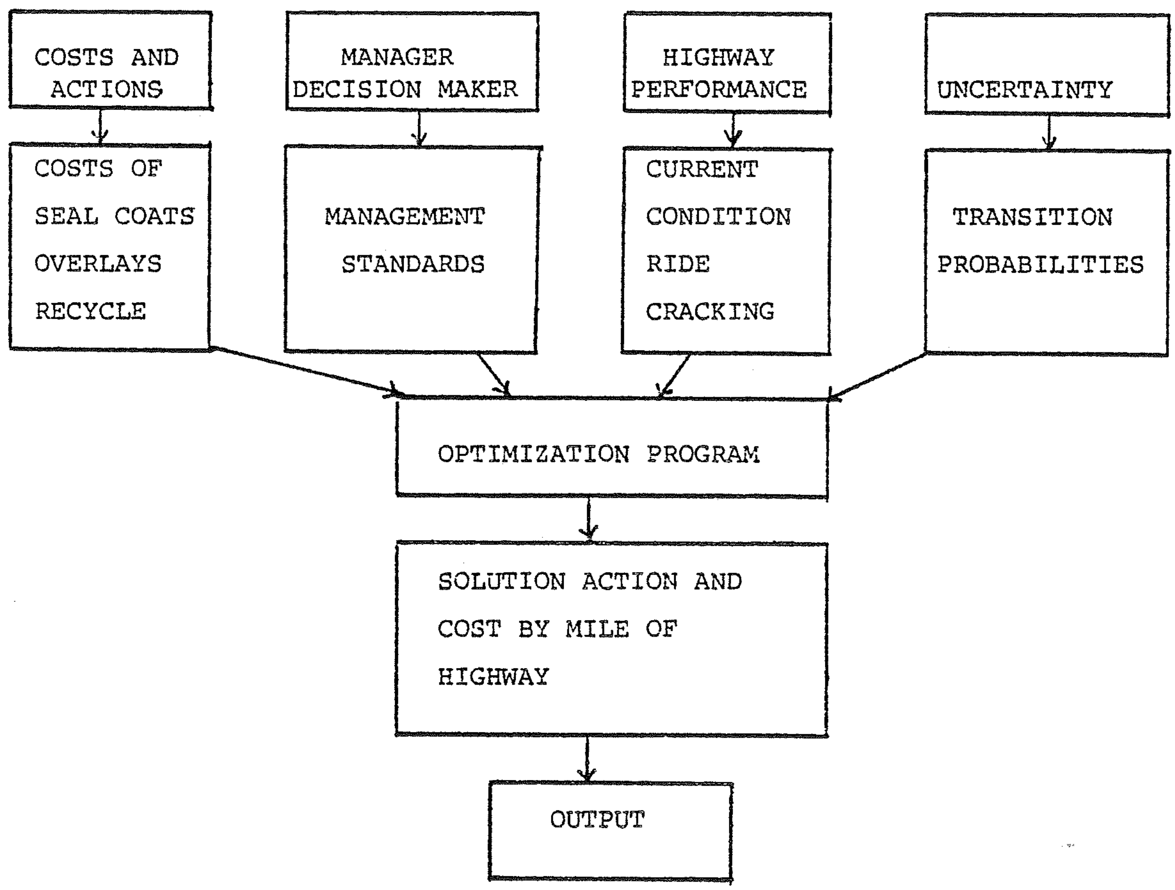
<u>Given all this data, how do you figure out what to do and when to do it?</u>

The systematic method in question is the Network Optimization System or NOS for short. Figure 3 describes the system graphically in block diagram form.

FIGURE 3

NETWORK OPTIMIZATION

INPUT



<u>This appears quite complicated, please explain the NOS a little bit, but don't get too technical</u>.

Current condition refers to an annual inventory of each mile of highway. This inventory determines the rideability, percent cracking and skid number for all 7,600 mileposts within ADOT's highway network. From the condition inventory each mile of highway is given an associated condition index number representative of its quality (good, fair or poor). Condition index classifications were derived from interviews between the Woodward, Clyde Consultants of Fred Finn and Ram Kulkarni and various top managers including District Engineers, Maintenance Engineers, Deputy State Engineers and Transportation Planning Assistant Director.

I noticed you had consultants involved in this study. Why did you need consultants, couldn't the ADOT staff have performed their work?

Consultants were employed because of their familiarity with decision theory and analysis. In addition it was felt outside consultants could conduct interviews and surveys with upper management, without any bias or animosity. Thus, both technical and psychological reasons dictated the employment of consultants.

Well, that's different from what I expected. Okay continue.

Condition index numbers for each mile are aggregated by summing the number of square yards of surfacing in each condition index. These groups of good, fair or poor miles of highway are sorted into three levels of traffic (ADT) and region (climatic zone), which gives nine groups. Square yards are converted to percent of square yards in each traffic and region group for each condition index. These percentages represent one input for asphaltic concrete (AC) pavements.

The system doesn't handle Portland Cement concrete?

It's true the computerized NOS portion of the system does not treat concrete at this time but ADOT's highway network contains relatively low mileage of PCCP. At present concrete pavement problems are handled outside the program. Also skid resistance is handled outside the program.

How are they handled?

Priority scores in terms of concrete roughness, cracking and skid resistance are developed. Likewise a set of low skid resistance miles is developed periodically. Those miles with high priority are listed for rehabilitation improvement.

I take it then that NOS is not a priority system, is that true?

That's partially true. NOS determines an action for each mile of highway per year. Thus a comparison of all miles relative priority can be obtained each year. Miles selected and action, however, interact with other constraints such as condition standards and funding, therefore, the final priority list is quite dynamic. Other inputs will help to explain this. Other inputs include a list of fixup strategies (seal coat, ACFC, Overlays, Overlays with Rubber Membrane or Heater Scarification) as well as routine maintenance strategies plus their associated costs per square yard. Additional inputs include the total number of square yards in each of the nine traffic-region groups. Another input is a list of strategies associated with each condition index. Thus a condition index representing a very good condition would call for only routine maintenance, whereas poor conditions might warrant several different possible fixup alternatives. (Thin overlay with or without asphalt rubber or heater scarification). The most important input is the management standards set for future pavement performance. Management specifies the percent of square yards that it wants in good condition and the maximum percentage it will tolerate in bad condition per three traffic levels (0-2000, 2001-10,000, 10,001+ADT). An optimization program selects the lease cost set of activities to take for each condition index to obtain the desired standards for as many years into the future as requested.

You mean as management changes its standards due to funding problems the list would change in terms of designated projects rather than just the length of the list.

Yes, you might say NOS offers a multitude of different possible lists dependent upon new management standards, as opposed to one single list. Thus NOS is capable of generating lists for different policies such as differing amounts of constrained funds, additional funds or improve conditions to name a few.

<u>What are transition probabilities?</u>

NOS is a probabilistic technique. When condition index groups were developed, perhaps many miles of highway went into each group. All miles within the group fell into certain ranges of ride and cracking. The transition probabilities are an estimate of what proportion of miles or square yards fall into smaller ranges within each condition index. Thus transition probabilities are representative of the distribution of miles or square yards within each condition index group.

Inputs are converted into a matrix and processed through a set of computer programs which determine the optimum least cost action to take for each mile per year, consistant with the constraints.

<u>The technical aspects of the computer programs do not interest me, however, does the program predict future condition using the previously determined equation?</u>

Yes.

<u>When overlays are called for do the designers have to follow the recommended action and what costs do they include?</u>

No, designers do not have to follow the actions strictly. Costs include surfacing material costs, mobilization, traffic control and engineering cost.

The following may help explain this process.

Individual miles calling for overlay are aggregated into overlay projects by using engineering judgement. The list of those miles of AC calling for seal coat, ACFC or overlay are distributed to each District and various interested areas (Plans and Planning). In addition, a list of low skid miles, poor concrete miles and exception projects (new jobs which appear to be prematurely failing) are distributed. Since NOS looks at five year periods, a five year preservation plan will be submitted to each District each year. Estimates of associated costs are given and optimally programmed over the five years.

Districts review this list along with their own list. A final list is decided upon which represents a compromise between all parties, funding constraints and the five year new construction program. It is hoped that NOS will be able to estimate funding levels and action, and that the final program will be at least within approximately 60 percent agreement the first year and 75 percent agreement in succeeding years. As pavement conditions, standards and funding constraints change, future preservation activities will have to change, thus an annual inventory and rerunning of NOS will be necessary.

<u>During this first year how close an agreement was there? And how did the Districts respond to this new system?</u>

Agreement was on the order of 75 percent over the entire state but this is not to say that Districts accepted the method. Indeed a revised set of overlay sections was developed. The purpose of the revisions was to bring the pavement management and district requests into closer agreement and to emphasize that the development of the annual and five year overlay plan is a cooperative effort between district and central offices. There was not sufficient time to reconcile all differences, however, attempts will be made this year to develop a dialogue between central and district offices much earlier, so that virtually all major differences can be worked out well before the project selection committee begins deliberations.

What about actual project designs?

In reference (2) the system for optimum project design is described. This system is called Selection of Optimum Maintenance Strategies for Asphaltic Concrete Pavements or SOMSAC for short. This sytem develops a set of feasible overlay strategies for the period of design selected. Solutions are based on utility theory rather than least cost.

Utility Theory? Please explain, what that is.

Utility theory was developed to allow decision makers to examine preference factors other than cost, such as, time, inconvenience, safety to name a few. These factors are called attributes in utility theory and they are converted to imaginary units such as expected utility units. These units imply a worth to each attribute, which is not necessarily in dollars. During this study decision makers were interviewed by consultants to determine the utility worth or importance they placed on various attributes. As an example a decision maker may have stated that safety was more important than cost.

Thus to maximize utility or worth safety would be appropriately weighted to give it greater importance. Thus, out of a set of possible actions, those actions with greater safety would be selected or prioritized first even though they cost more.

<u>So utility would be used to more closely reflect the decision makers true preference for some activity or action. Isn't this different from NOS?</u>

Yes, in NOS actions were taken to minimize cost over the entire network, whereas under SOMSAC actions are taken to maximize utility or benefits without regard to cost.

<u>Doesn't this create a conflict?</u>

Yes and no. Philosophically there probably is some conflict, however, experience has shown the two answers do not generally differ that dramatically. Case by case differences do occur but over the entire network the average costs are quite similar.

<u>Does SOMSAC predict future ride and cracking like NOS?</u>

SOMSAC was developed in 1976 and at that time cracking was not an inventory test. Only ride and skid prediction models were developed. Like NOS the prediction equation calculated the expected change in ride as a function of region, Dynaflect deflection, annual 18 kip equivalent axle load and age of pavement. If an overlay was called for then thickness of overlay became a factor as well. Skid number was a function of region, age, annual 18 kip equivalent axle loads and aggregate type. Experience has shown that skid number was not very predictable due to various surface treatments (flush coats, seal coats, etc.) which alter the pavement surface. If no such activities occurred on the AC pavement then the prediction could probably predict aggregate wear (polishing) reasonably well. In reference (7) it was shown that the SOMSAC ride prediction model was as good as the NOS model, thus conventional factors could be used for prediction.

Does this mean NOS could be substituted for SOMSAC or vice versa?

For predicting ride this would be possible. It should be recalled that for NOS only region and present ride are needed to compute expected values for all 7,000 miles. For the SOMSAC model; region, traffic, age and deflection would be needed by mile, which is at least triple the information. For design this information is routinely collected.

What about cracking in SOMSAC?

Quoting from report (2),

"It is pertinent to discuss the use of deflection as a determinant of future roughness since a great deal of reliance is being given to the role of this particular measurement. A number of field studies have shown that deflection can effectively be used as a determinant of performance; three of the most notable would be represented by results of the AASHO Road Test (1962), studies by the Ontario (Canada) Ministry of Transportation and Communication (1965) and developments of the Asphalt Institute (1969). For over 20 years the California Transportation Laboratories have used deflection as a design parameter. Their latest procedures are described in

Structural Overlays for Pavement Rehabilitation." With this background of results, and others, the Consultant considered deflection a reasonable proxy for pavement in-situ strength and condition (cracking). ADOT's plans would be to include a cracking model in SOMSAC in place of skid number.

It appears that ADOT will need to do some back tracking from NOS to SOMSAC. Was the project to network approach the correct one?

At that time project optimization seemed very difficult and network optimization impossible. Even when the projects (6) and (7) began the consultant only gave ADOT a 50/50 chance of success. Since the Network has more application to more problems, other agencies would be wise to start with the network approach.

What about #5? Does such monitoring take place?

ADOT has developed a construction history file which contains date of construction, layer type and thickness. Figure 4 gives an example. At present ADOT files virtually all construction tests by project number, type of material and test results. Ultimately a synthesised version of this file will be stored in the PMS data base. Surface routine maintenance activities are stored by the maintenance section in a file called PECOS. PMS accesses this file and stores it in an abbreviated form in the PMS data base. Thus both construction and routine maintenance activities are monitored as they occur.

<u>That's a lot of data, can it be retrieved efficiently as per #6?</u>

Considerable time was spent developing a data base which could accomodate the needs of various users. A heirarchial file was developed in order to improve retrieval time. This file or data base is called an Information Management System (IMS), it is so structured that each record has a unique location which can be found by keying in certain identification codes, making it possible to go directly to the desired record or records without having to search through all previous records. In a way, the data base is similar to a library. By knowing the title it is possible to go to book by using the alphabetical card catalogue without having to look at all the other book titles or books. By knowing the highway location (route, mile post, direction) it is possible to look up information about that mile-post and have it appear on a cathode ray tube (CRT) terminal in about 1 to 2 minutes.

<u>That sounds pretty good, who uses it?</u>

Extensive use is made by research, designers, planners, districts, maint-enance and pavement management personnel.

<u>Has the cooperation and communication (7) been good?</u>

Other areas of the department have been communicating and the pavement management branch has tried to cooperate as much as possible. The communi-cation has not always been positive or encouraging. Some still think the computer is taking over and resent it. In reality the computer is only being used as a tool to furnish information it cannot make decisions or dictate policy, but it can help determine the consequences of such activities. Some do not like the calculations and claim the data has misrepresented the calculations and claim the data has misrepresented the situation. In some ways they are correct. The data base represents the most important portion of the pavement management process. Without appropriate, accurate and timely data no management system can function as it was intended. Considerable emphasis is placed on the data collection process; the data are reviewed, corrected, edited and sometimes retested in order to guarantee their usefulness. ADOT's experience has been that timely data is very important. Data two or more years old generally is questionable due to changes caused by construction and/or maintenance.

In closing ADOT has a functioning PMS that has been in use for one year. This system addresses both network and project level pavement management problems. The system is dynamic and flexible enough to accomodate the type of evolutionary changes that will surely occur in the future.

GBW:ib
07/29/81

FIGURE 4
PAVEMENT MANAGEMENT INFORMATION SYSTEM