BOOK REVIEWS

Pavement Management for Airports, Roads, and Parking Lots

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REFERENCE: Shahin, M. Y., *Pavement Management for Airports, Roads, and Parking Lots,* Chapman & Hall, New York, 1994, ISBN: 0-412-99201-9, 450 pp.

Quantitative Analysis, also known as Management Science and Operations (or Operational) Research, can be of significant utility in situations where there is, first, a significant amount of money involved (the analysis is quite expensive, so there has to be a significant potential payoff) and second, the underlying physical situation is amenable to either mathematical analysis or simulation. The allocation of maintenance dollars to a road network is on its face a clear candidate for using quantitative methods. The amount of money involved is extremely large—multiples of millions for many entities—and the degradation of roads is—like all aging phenomena—inherently probabilistic, making it a fertile ground for quantitative modeling. Many, if not most, road networks are maintained on an *ad hoc* basis, often supervised by those who worked their way up from the ranks; the ground to be worked by mathematical optimization techniques is thus often virgin soil, implying that analytical techniques can generate quantum rather than incremental improvement. In short, it would seem that the tools of quantitative analysis should be able to be applied fruitfully to the pavement management process.

This book by M. Y. Shahin, a researcher at the United States Army Construction Engineering Research Laboratories (CERL), plumbs the topic of applying quantitative analysis to the maintenance of road networks. For those who want the short answer, if you are *involved* in pavement management decisions, you may well want to buy this book, despite its many, many shortcomings. And then, you should buy MicroPAVER, the computer program for pavement management that was developed at the CERL.[1] The reason is simple: if you can wade through this poorly written tome, and successfully implement but one idea from the book or by using MicroPAVER, the payoff will be orders of magnitude greater than the cost of the book and the program and the time it took you to slog through them. If you are a researcher working in the area of pavement management decisions, be warned that the source code for PAVER/MicroPAVER is reportedly not available, a serious shortcoming to anyone who wants to modify the methods used in the program. And there exist other pavement management programs, an important fact not noted in this book.

Pavement Management describes a multistage analysis approach to pavement management:

- First, you subdivide a pavement network to uniquely identify each and every area of pavement. You divide the network into branches, then sections. In effect, one gives a "serial number" to each section of the pavement network. All of the pavement in a section should be of the same pavement type and share similar age, history, condition, traffic, geography, and drainage characteristics. For inspection purposes, to characterize the condition of a pavement section, the section is further divided up into yet smaller sample units.
- The condition of each section, or of a random or systematic sample of segments, is evaluated. A number of techniques are described to characterize pavement condition: survey and rating, nondestructive and destructive testing, and skid-resistance measurements.
- Pavement condition prediction is accomplished using statistical techniques, including constrained polynomial regression.
- A global (network) management plan is formulated.
- For each project identified in the global plan, alternatives are discussed, and by quantitative analysis of the project maintenance alternatives, a specific alternative is selected.

A number of elements make this book worth obtaining:

- There is an extensive set of appendices containing report forms, photographs depicting pavement with varying levels of different flaws, and charts that help quantify the conditions illustrated in the photographs. If you have no other similar reference, these elements alone justify the purchase of the book.
- The chapter on "Network-Level Management" is outstanding. It starts out by identifying who the chapter is written for and what questions can be answered in the chapter. Sample management reports are presented. While those reports are developed using MicroPAVER, their format and content are more generally applicable. Of real interest is the concept of the critical Pavement Condition Index (PCI) range. Essentially, keeping the pavement resources in good condition—above the critical PCI range—will result in lower long-term costs. The implementation of the concept is rather fuzzy: engineering judgment, the author calls it. Nonetheless, critical PCI is a concept worth quantifying and implementing. Related to the idea of a critical PCI is a graph of PCI versus cost which hammers home the idea of well-maintained roads actually saving money. Another chart shows the cost effects of different Maintenance and Repair (M&R) funding decisions. It too reinforces the concept that saving money on M&R does not necessarily save money; it often costs money.
- PAVER, which was developed by the author at the United States Army CERL is endorsed and supported by the American Public Works Association. This is a very significant endorsement.

There are however, many, many problems with the book:

- The preface indicates that the primary objective of this book is to present pavement management technology to engineering consultants, highway and airport agencies, and universities. No one seems to have given thought to how the book should be aimed to benefit that disparate audience; *Pavement Management* ends up being too complex for the average road supervisor, too trivial for a quantitative analyst with a road maintenance background, and not operationalizable for an engineer with a strong mathematical

[1]MicroPAVER is reportedly available from two sources: The American Public Works Association ((816)-472-6100 X591—ask for John MacMullen), or The University of Illinois School of Continuing Education ((217)-333-2882—ask for Beth or Lynn)). The cost is about $400 from the former source and about $350 from the latter, both including updates and support for one year.

background. The lack of the availability of the computer source code for PAVER severely limits the utility of the book (and the program) for research ends.

- In fact, *Pavement Management* is less a treatise on pavement management in general and more a not-too-gentle introduction to PAVER and MicroPAVER. The book does not mention the ten or so other pavement management programs, both public domain and proprietary, that are currently on the market. None of this should suggest to you any lack in PAVER/MicroPAVER. Rather, the failure to discuss pavement management programs other than PAVER (written by Shahin) suggests either myopia or a severe case of Not Invented Here on the part of the author.
- Neither the author nor the editor seems to have given thought to what material is *important* in a book on pavement system management; the author wastes trees with a detailed exposition of bivariate regression analysis (fitting a straight line to a dataset by finding the "optimal" slope and y-intercept), which can be found in *any* introductory statistics text, and then uses a fourth-order-polynomial constrained regression to predict pavement condition. Constrained-polynomial regression is found nowhere save advanced texts. Knowing the details of linear regression will not at all bridge the chasm between knowing no regression analysis and understanding constrained-polynomial regression.
- The editing is worse than awful: it is narcoleptic. It appears that the book was stapled together from Shahin's (and others) research monographs. No effort was made to make the different papers, which became the book's subsections, cohere. The result is a muddle. Some examples:

Equation 4-1 is given in 'FORTRAN format':

$$\text{AREA} = (6/\text{DO})*(\text{DO} + 2*\text{D12} + 2*\text{D24} + \text{D36})$$

It is also found in various algebraic formats, with different subscript designators for the variables:

$$A = \frac{6}{D_0}(D_0 + 2D_{12} + 2D_{24} + D_{36})$$

and

$$\text{AREA (INCH)} = 6\left(1 + 2\frac{D_1}{D_0} + 2\frac{D_2}{D_0} + \frac{D_3}{D_0}\right)$$

where the D_1 corresponds to D_{12}, D_2 corresponds to D_{24}, and D_3 to D_{36}. This is, for someone trying to learn the material, a recipe for confusion.

The calculation tutorial for the PCI index is arguably the most complex operationalized procedure in the book. Needlessly complicating that tutorial is the fact that the defect graph in the example is for type 41 defects (Alligator cracking) while the calculations are performed for a defect of Type 48 (Longitudinal/Transverse cracking). Given that this discussion is tutorial in nature, where readers are attempting to figure out this complex process, this failing is not excusable.

The chapter on "Project Level Management" appears not to have been content-edited. The purpose of dividing a technical book into chapters is to compartmentalize to the extent possible different areas of knowledge. What we have here is a book which has far too much chapter-to-chapter dependence as a result of gross editing lapses.

This chapter starts by making the point that the history of the road section is of great importance and lists information to be gathered: construction and maintenance, traffic history, PCI, testing, and drainage (so far, so good). The chapter then takes a tangent to go into detail on destructive and (again) nondestructive testing, material that should have been, and to a large extent was, covered earlier, in the chapter entitled "Non-Destructive Testing." In the middle of all of this is a four-page chart of typical California Bearing Ratios for various soil types. Not related to any example in the text, this chart clearly belongs in an appendix. When the chapter gets back on track, and on point, discussing pavement evaluation, it again becomes useful, discussing how one must consider overall (and variation in) pavement condition, the rate of deterioration, and the evaluation of pavement defects and their causes, and so forth. Unfortunately, this section of the chapter reads like it was stripped out an old PAVER instruction manual. Nothing else that I can think of could explain the following last step:

> Step 9: Comments. Any constraints in choosing an M&R alternative should be identified in the comments section.

- The book is heavily padded. While the pavement condition photographs and charts discussed above could arguably be considered padding (they take up almost 200 pages in a 450-page book), they are potentially very useful. On the other hand, there are simply too many half-page photographs of cars and trucks equipped with testing equipment. (When you leave the sixth grade, you, perhaps regretfully, give up picture-book texts.)
- PAVER is a work in progress. As such, it has many rough edges and some poorly developed areas. Some examples:

Some of the modeling is third-rate. Remarkably weak, for example, is the Markov Chain analysis for pavement deterioration. Markovian analysis assumes that state n of a system is dependent only upon state n–1; that is, if one knows the state of a system "today," the probability distribution of the system "tomorrow" is completely specified. A *Markov Chain* is a thing that behaves in a Markov manner where discrete changes appear at discrete instants, once per period. Pavement condition, in fact, as expressed by the PCI, is a continuous metric characterizing a continuous process. The author, however, censors the data by looking at the condition period by period. This is presumably done to force the process into a Markov-Chain model. Shahin further censorially assumes that PCI will either stay the same or decrease by ten points. The Markov *Process* model, which has been around far longer than I have known about it would handle the process without censoring it.

Even given the use of the Markov Chain, rather than the Markov Process model, poor use is made of it. The Markov model is simply used to illustrate the fact that if you do not maintain your roads, they will—Newt Gingrich take note—go back to being donkey paths. This is based upon the not-stated observation that, without M&R, the model is ergodic; it has a steady-state solution (donkey paths). To make the Markov Chain Model more realistic, first, there is nothing inherent in the Markov Chain Model which forces one into the dichotomous 0-or-10-point PCI decrement. Secondly, what was not shown, but should have been, is how Markovian analysis can

be easily and effectively used to analyze the long-termcost and effects of implementing different maintenance policies.

Much of the mathematical modeling is inadequately or not at all explained. The procedure for calculating the PCI of a sample of roadway, runway, or parking lot is developed in great detail, but with none of the background, and no overview or rationale, to make sense of the steps of this rather intricate dance.[2] Given that Shahin posits this book for "universities," this failing is significant.

Some of the approaches have downsides that are not explored. Given that one calculates the PCIs for each sample in the section, the aggregate PCI is calculated by averaging the sampled PCIs. The author notes that other samples may be taken, for example, to characterize an "exceptionally bad condition." He goes on to characterize the aggregate condition of the section by taking a weighted average of the quasi-randomly sampled areas along with the other samples. I have serious reservations about using such a weighted average to characterize the condition of a section. By adding enough exceptionally bad sample areas to a section calculation, one can change the order of the PCI list, or get a PCI above a critical level needed to precipitate a repair. In a world where squeaky wheels get greased and the politically powerful have the best-paved streets (or the worst, depending upon their feelings about local traffic), the management tool described in this book could be used as a way of rationalizing noneconomic decisions. I am not suggesting that assessing exceptionally bad or other anomalous features should not be done; rather, that these values should not go into the calculation of the PCI for a section. Better yet, put the anomalous areas into their own sections, or repair those exceptional areas without regard to the rest of the section. I note that Shahin's extrapolation of the amount of pavement distress in this book section correctly excludes the exceptionally bad pavement areas from the extrapolation process.

Some of the analysis is wrongheaded. The formula for the number of samples needed to evaluate a road system contains the standard deviation of the PCI. The standard deviation is generally not known before the testing starts. (The author suggests starting values for the standard deviation.) Thus, as the sampling progresses, the standard deviation will change, and thus the sample size will change. This would not be a problem if the sample regions were selected randomly. But Shahin recommends a systematic approach, where only the first sample location is randomly selected, and the rest uniformly distributed throughout the section. In fact, if the sample size changes as the sampling progresses, so will the systematic sampling plan. I am not saying that this cannot work; rather, by not giving the fellow trying to use this the background of how the sample size formula comes about, he forces the user to make decisions based upon faith. Shahin writes that the range of PCI values (the largest PCI value minus the smallest) can be substituted for the standard deviation. In fact, the range and the standard deviation should *never* be used interchangeably. (For one thing, the range has an inordinate sensitivity to outliers. For another, the range became effectively obsolete for all but back-of-envelope analysis when scientific calculators became readily available, over 20 years ago.)

Finally, the idea of a random start is not appropriately amplified. One does not "select at random" a number; one provides a process for generating a random number. Comedian Henny Youngman's business card had the numbers 1, 2, 3, and 4 on the front, and an instruction to "pick a number." (Reader, do this in your mind.) On the back was the statement: "All S#$%{#&s pick 3." (Also on the back was "Henny Youngman, Mathematician," and his phone number.) Mathematician Youngman knew that people have strong biases when asked to select numbers; so too should have Shahin. This book is not a monograph targeted mainly at researchers; many of the readers will be far less mathematically sophisticated than the author, and would not know of the problems in selecting at random a number.

- The issue of tort litigation is not addressed. Rational allocation of maintenance budget dollars is a key element in defending against civil lawsuits against road owners. First, optimally maintained roads will, *cet. par.*, minimize the number of lawsuits by minimizing the number of pavement-precipitated accidents: given the tax dollars budgeted for road maintenance, an optimal, rational maintenance policy will allow in an overall fashion the safest possible road network. Second, the very existence of a rational-maintenance-dollar-allocation scheme is itself a defense in some areas.
- The book cries out for an interchapter example: *An Analysis of the Maintenance Policies of the Town of Mudville,* so to speak. There is in the chapter on project management an example of the type sorely needed throughout the book. It presents sample filled-out forms and exploration of the available alternatives. It lacks only photographs of the area under analysis, not a major omission.
- Significantly, the source code (the computer instructions that get compiled into the user version of the program) are unavailable. This would make PAVER/MicroPAVER worthless for research, because you cannot change a subroutine. (For example, let's try unconstrained quadratic regression instead of constrained quartic.) By distributing the source code (putting it on the Internet would be an effective, cost-free way for the CERL to accomplish this), researchers would have the opportunity to obtain, permute, and, hopefully, improve PAVER. CERL might actually benefit from such activity. The UNIX operating system, arguably the

[2]*Simply* put, for each type of defect in the pavement, a "deduct value" is determined by means of a graphical look-up, which considers the amount and severity of the defect. The book contains detailed tables and graphs, as well as carefully reproduced photographs, to determine the defect severity. After the defects of each type are determined by inspection, picked off the graph, totaled, and sorted in descending order, one then determines the "maximum number of defects." Again in this blind dance, it does not inspire faith when Shahin writes: "If only one individual deduct value (or none) is >5 for airfield and unsurfaced roads, or 2 [is that >2 or *exactly* 2?] for surfaced and unsurfaced roads, . . ." If one were scoring an unsurfaced road, would one use the ">5" target or the "2" target? In any case, for each defect, the number of defect values is limited by a formula-derived value based upon the largest number of defect values for any defect in the sample. Based on the number of deduct values greater than 5 (or 2) (call it q) and the sum of the uncorrected deduct values, look up on another graph: the Corrected Deduct Value (CDV) graph. Finally, iteratively decrement q one by one, starting with the smallest deduct value greater than 5 (or 2), subtract from that value 5 (or 2) and look up again on the CDV graph another CDV, using the decremented q and the reduced deduct values. Repeat this until q is decremented to one. Each time you do this, you will get another CDV value. Pick the largest of the CDVs and subtract it from 100. That's the PCI. I hope you got that, because there is absolutely no way that the reader can even begin to understand what is going on underneath this intricate mathematical minuet.

most capable microcomputer operating system available, benefited greatly from its public release, and still benefits today from user-generated improvements.

- But the most glaring problem with the book is that it relies heavily—heavily—on PAVER/MicroPAVER. But unlike so many technical books in print today, no disk or CD with PAVER or MicroPAVER is supplied with the book. No detailed flowcharts are provided that show the workings of the program. This makes the results in the book black-box results; they might just as well have come from a *deus ex machina.* Again, PAVER was developed with public funds; it is technically the property of the public.[3] An unsupported or even a demo version of the software would cure that problem for those reading the book. Given that this software will likely need support for all but the most computer savvy, giving away a free version of the software could prove to be a boon for those distributing the not-quite-free versions. (Look at the fact that many UNIX users purchase commercial, supported versions of the product, even though free versions abound.)

Finally, there are many interesting questions in this book, and in PAVER/MicroPAVER, which this book did not address. This is not meant to be critical of the author; rather, it is meant as suggestions for the second edition which, it is hoped, will be edited by one with as much dedication as the author had in developing this work.

[3]The two sources for the program are not, technically speaking, selling the program. They are charging for the cost of distribution, updates, and support. And the cost, of the order of magnitude of the cost of a word processor or a spreadsheet, is, in fact, quite fair. I note in passing that nowhere in the book (at least, nowhere that I could find) is the availability of and sources for MicroPAVER given. I obtained that information directly from the author.

- The two-stage method used to select pavement sections and then M&R alternatives might be subject to suboptimization because of integer effects at the project level. This is especially true in situations where there are relatively few projects expensive in proportion to the total budget alternatives; that is, the procedure whereby one first selects those sections of road to be improved, and then selects the optimal way of improving the selected sections, might end up with selecting sections and projects that would be different (and less globally optimal) than if each section/M&R alternative was considered as a separate decision possibility. The two-stage method used by Shahin is far simpler to implement, but some discussion of integer effects is certainly in order.
- There is a good discussion of why a moving average acts as a filter in the section on road profile-measuring, but the rationale for selecting the number of samples within the base length is not given. Surprisingly, the use of frequency analysis and frequency analysis tools, e.g., Fourier analysis, is not discussed. This would be useful, as vehicular suspension response is characterized in the frequency domain, and not the time domain.

If you have read this far, you can see why I have given this book a mixed review. I spoke to the author at CERL. (He did not know that I was reviewing his book.) He was gracious in answering my questions and clearly interested in disseminating the CERL-developed, pavement-management techniques. So, again, if you are actively involved in pavement management, buy the book and MicroPAVER. If you are a researcher, buy the book and start hollering for the PAVER source code. And if you are the publisher, arrange to ship an unsupported (or at least, a demo) version of PAVER/MicroPAVER with the book, and get your editor some *strong* coffee before editing the next project.

BOOK REVIEWS

Engineering Materials Technology: Structure, Processing, Properties & Selection, Second Edition

Reviewed by George Laird, Ph.D., Albany Research Center, U.S.B.M., Albany, OR 97321-2198.

REFERENCE: Jacobs, J. A. and Kilduff, T. F., *Engineering Materials Technology: Structure, Processing, Properties & Selection, Second Edition,* Prentice Hall Career and Technology, Englewood Cliffs, NJ, 1994, ISBN: 0-13-278284-7, 663 pp.

As a research scientist dealing with many specialized books on metals, ceramics, fracture, mechanics, etc., it was a pleasure having the opportunity to review a broad-based textbook on materials technology. The authors are to be commended on their presentation of the rapidly changing materials world and, in particular, their emphasis on the environmental aspects of materials selection and usage.

The book is intended primarily for students enrolled in two-year technology programs or perhaps for students who would like to know more about the application of materials in today's world. The book might be considered to have two general sections. The first section gives the reader a basic introduction to materials science with chapters on the "Nature and Family of Materials," "Processing and Structure of Solid Materials," and "Properties, Degradation, and Failure of Materials." The second section provides more specific information on the four main classes of materials: metallic, polymeric, ceramic, and composite. Additionally, a chapter is dedicated to just electronic-related materials. In this last chapter, dielectric, magnetic, piezoelectric, and other electronic properties are explained and examples of their usage are given. The authors have also provided a brief appendix of material properties to guide the reader as to what sort of typical mechanical, thermal, and chemical properties can be expected from common plastics, elastomers, metals, ceramics, and glasses.

Overall, the book is well organized and well presented. At the beginning of each chapter, an interesting thought or two is thrown out for the reader to ponder. From this questioning basis, the reader is lead into further exploration of the materials world. I enjoyed the way the authors presented the "dark" side of materials selection; for example, the way plastic pipes with metal/plastic compression fittings were first selected for use in the municipal water market. After installation, leaks occurred around the compression fittings leading to some controversy and acrimony toward the engineers who specified these "new" piping systems. In fact, I found the authors' critical thinking of many materials and material systems very refreshing (e.g., their comments on biomimetics on page 60).

Another aspect of this book is their excellent coverage of wood materials (within the polymeric section of the book—although some might consider wood a composite). A detailed examination of the nature of softwoods (main construction wood in the United States) is presented along with many examples of how the anisotropic properties of wood can affect its usage. Construction techniques involving wood products are presented and, of course, the advantages and disadvantages of using wood products in design are discussed.

To give an idea of how their chapters are constructed, I will use as an example the chapter on "Composite Materials." The reader is first introduced to an advanced composite material commonly known as Gore-Tex®. This fabric composite usually consists of a nylon outerlayer with an inner membrane coating (or layer) of polytetrafluoroethylene (PTFE). I liked the authors use of this example since it causes the reader to rethink their typical assumptions about what constitutes a composite material. Some definitions are then given and the reader is then questioned: "Why use composites?" A list of 14 reasons are given; e.g., to increase stiffness, strength, or dimensional stability, to reduce weight, to reduce costs, etc. A brief historical perspective on composites is given, followed by a section on "Constituents of Fiber-Reinforced Composites." Throughout the authors' work, emphasis is placed on manufacturability, cost, and environmental aspects of the material selection process. For example, "Boron is more expensive than graphite and requires expensive equipment to place the fibers in a resin matrix with a high degree of precision." Structure and properties of composites are discussed with most of the discussion centered on macrocomposites (i.e., plastics or metals reinforced with fibers or particulates). Mechanics of composites are presented (e.g., Rule-of-Mixtures) with a brief coverage of failure and fracture of composites. The bulk of the chapter then covers specific types of composites (glass fiber reinforced plastics, metal matrix composites, laminar composites, and a variety of loss common composite types) with discussions on manufacturing and specific advantages and disadvantages of each composite type. Near the end of this chapter, a glossary appropriate to composites is presented; e.g., "Scrim is a low-cost reinforcing fabric made from continuous filament yarn in an open-mesh construction." The reader is then introduced to some applications and alternatives in composites with a lengthy discussion on the composite automobile. The necessity of recycling composites is brought forward with arguments made in favor of setting up a nationwide "recycling infrastructure" to reroute polymers toward positive economic usages (versus negative economic uses as in landfill contributors). At the end of each chapter, a "Self-Assessment" section is given (35 questions in this chapter) followed by references and related materials (30 publications and 15 periodicals are cited), and lastly, a brief list of "Experiments and Demonstrations in Composites" (e.g., Ref *1*).

Every book has its strengths and weaknesses, and although the book contains several minor points that may annoy the experienced materials engineer or scientist, it must be kept in mind that the book is intended as an introductory text—a gateway to the materials world. From this vantage point, my only strong concern is the limited citation of other books dealing with materials science and technology. From my perusal of the reference list at the end of each chapter, ASM Handbooks or specialized ASTM publications dominate the reference list. Although these publications provide an excellent starting point, there are still many other excellent sources on materials technology. For example, under the "Metallic Materials" section (18 references) there was no listing for a general metallurgy book (e.g., Ref *2*) or in the "Properties, Degradation, and Failure of Materials" section (18 references) there was no listing for general fracture and failure books (e.g., Ref *3*).

Additionally, the authors did not include any references to general materials science books (e.g., Ref *4*). Since engineering materi-

als technology deals with students new to the field of materials, I feel the authors have a special duty to have extensive pointers to other literature in the field; that is, to provide a wealth of references for inquiring minds that would pursue further study in the field of materials technology.

Overall, the authors have done an excellent job on producing a well written and interesting introductory textbook on materials technology. I enjoyed reading the book and found the authors' questioning viewpoints toward the material selection process quite useful. The student should come away from this book with an open and inquisitive attitude toward materials selection and usage with a well balanced perspective on the costs, manufacturing issues, and environmental aspects of the material design process. In summary, I would heartily recommend this book to educators and people new to the field of materials technology.

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