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RESEARCH RESULTS DIGEST

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Pavement Marking Assessment System (PAMAS)

This NCHRP digest introduces a computer program that will ease the computations required to carry out the methodology described in NCHRP Report 392, "Pavement Marking Materials: Assessing Environment-Friendly Performance." NCHRP Report 392 contains the findings of NCHRP Project 04-22, Pavement Marking Materials: Health, Environmental and Performance Assessment, conducted by Anthony L. Andrady, Research Triangle Institute, Research Triangle Park, North Carolina. The computer program was developed by Dr. Andrady and staff from Applied Technologies, Cary, North Carolina. The digest was prepared by Dr. Andrady and Lloyd R. Crowther, P.E., NCHRP Senior Program Officer.

INTRODUCTION

This digest contains a brief description of and the operating instructions for a computer program that simplifies the semiquantitative process for measuring the engineering performance; environmental performance, including the impact of volatile organic compounds (VOCs); and health concerns, including an evaluation of the hazardous air pollutants (HAPs) of various classes of conventional pavement marking materials used for highway stripes. This program is especially timely because the United States Environmental Protection Agency (U.S. EPA) is expected to regulate the permissible amounts of VOCs in paints and coatings early in 1998. This regulation might proscribe the use of most presently available solvent-borne paints and some water-based paints.

BACKGROUND

Prior to this research, information concerning VOCs and HAPs was not readily available to state departments of transportation (DOTs). The contents of *NCHRP Report 392*,

"Pavement Marking Materials: Assessing Environment-Friendly Performance," which describes the findings of NCHRP Project 04-22, *Pavement Marking Materials: Health, Environmental and Performance Assessment*, conducted by Anthony L. Andrady, Research Triangle Institute, Research Triangle Park, North Carolina, are of immediate interest to members of the pavement marking community and their managers and policymakers. The research evaluated the most common categories of commercially available pavement marking materials used in the United States. These materials include (1) solvent-borne paints, (2) water-based paints, (3) thermoplastic markings, (4) tapes, (5) raised pavement markers installed using an adhesive, and (6) several field-reactive marking systems (involving the mixing of two separate reactants immediately prior to application).

Although a brief description of the Pavement Marking Assessment System (PAMAS) is included in the program introduction below, a thorough understanding of the principles described in *NCHRP Report 392*, which can only be gained through reading that report, is required to derive the full benefit of the program. While it is not imperative that the

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user understand the theoretical basis of the methodology, the program will prove most valuable to users who are comfortable with the principles involving the description and measure of the attributes used to quantify both the engineering and environmental performance of the marking materials being assessed, the structure of the decision tree involved, the assignment of weights throughout the decision tree, and the role and validity of the default values available in the program.

RESULTS

Versions of the program for Windows 95 (PAMAS95) and Windows version 3.1 (PAMAS31) may be downloaded from the Cooperative Research Programs' World Wide Web home page *http://www2.nas.edu/trbcrp* by clicking on NCHRP All Projects in the right-hand column, followed by 4 General Materials, then 4-22. The project description will appear; the programs are hypertexted near the bottom of the page (PAMAS95 or PAMAS31), as are copies of the manual (PAMASMW6.doc for Windows 95 and PAMASDMW2.doc for Windows 3.1). Both manual documents are essentially the same but are readable by the different operating systems. The contents of the manual are reproduced beginning on the next page.

PAVEMENT MARKING ASSESSMENT SYSTEM (PAMAS) MANUAL

INTRODUCTION

Why An Assessment Is Needed

Selection of a pavement marking material is generally made on the basis of engineering performance and on the cost of the marking material. The key characteristics most often considered are the retro reflectivity, durability, and lifecycle cost. Numerous other factors such as the ease of use, the availability of reliable contractors, or even previous experience with different marking systems generally influence the choice of the pavement marking material selected for a specific project.

Starting in 1998, this selection process becomes more complicated because additional legal requirement on the volatile organic compound (VOC) content in the marking material will have to be met. Only a maximum of 150 g per liter (or 1.25 lb per gallon) of VOCs will be permitted in a coating material used for pavement marking applications. Most conventional solvent-borne traffic paints cannot meet this requirement and cannot be used after the rule becomes effective. This ceiling value for the VOC content may be revised to a lower value in the near future.

Some pavement marking systems contain volatile compounds that are also classified as hazardous air pollutants (HAPs). The allowable HAPs in coatings are also expected to be regulated at a future date. Several classes of pavement marking materials contain HAPs and will be affected by this impending legislation. These HAPs may present a health hazard to striping crews that are routinely exposed to them. Little information is available on the level of exposure of the crew to HAPs and on the specific health impacts of such exposure. Yet, it is prudent for the pavement marking community to be cognizant of this aspect of marking materials.

The selection of pavement marking materials on the basis of engineering performance alone is carried out informally, often based on past experience and on a few selected performance criteria. With the inclusion of factors such as the VOC content and potential health impacts, an additional set of performance characteristics, referred to as "environmental performance" characteristics, need to be addressed. These being very recent developments, most engineers have little or no experience to guide them in selecting environmentally compatible marking materials. A decision-making tool that guides the engineer in the selection process is therefore useful. PAMAS (Pavement Marking Assessment System) is such a tool, and it allows the engineer to take all factors into consideration in selecting a marking material that has the best engineering performance as well as the environmental compatibility within the cost and performance constraints specific to the situation. PAMAS cannot make the selection of a marking material on behalf of the engineer, but it can assist in making the best possible selection.

The above introduction is a summary of the "Introduction" in *NCHRP Report 392*, "Pavement Marking Materials: Assessing Environment-Friendly Performance." A detailed discussion of the analytical approach used in this software is contained in the report. A copy of the report can be obtained from the Transportation Research Board, National Research Council, 2101 Constitution Avenue, N.W., Washington DC 20418, telephone: 203/334-3213.

What Is PAMAS?

PAMAS is a software package based on decision analysis theory. It allows the user to calculate two numerical indices for each candidate material, based on information on the marking materials provided by the user. These indices quantify the overall engineering performance and the overall environmental performance of a candidate marking material. PAMAS plots these values on a two-dimensional grid allowing the user to compare the overall performance of two or more pavement marking materials.

What Characteristics of the Marking Material Are Used in This Assessment?

A detailed discussion of the algorithm used in PAMAS software is available in *NCHRP Report 392*.

In summary, the methodology recognizes six **goals** associated with the selection of a pavement marking material. Of these, four are related to engineering performance and two to environmental performance. They are as follows:

Engineering performance goals

- High visibility
- High durability
- Convenience
- Low cost

Environmental performance goals

- Low VOC level
- Health and safety considerations

Associated with each goal are one or more **attributes** of the marking material that can be measured. Each attribute is quantified by a **measurement**. The relationship between the goals, attributes, and suggested (default) weights is shown in Figure 1. A detailed description of the attributes can be found in the *NCHRP Report 392*.

The engineering performance goals are expressed in terms of six attributes:

1. Change in retro reflectivity of a stripe (T_{100} months);
2. Change in the appearance of a stripe after 1 year of use (rating of 1-10);
3. Change in durability after 1 year of use (value of 1-10);
4. Ease of use (application and removal) of the marking material (rating of 1-5);
5. Storage stability (rating of 1-5); and
6. The annual cost of the material based on a 6-year period (value of $0-$x.00).
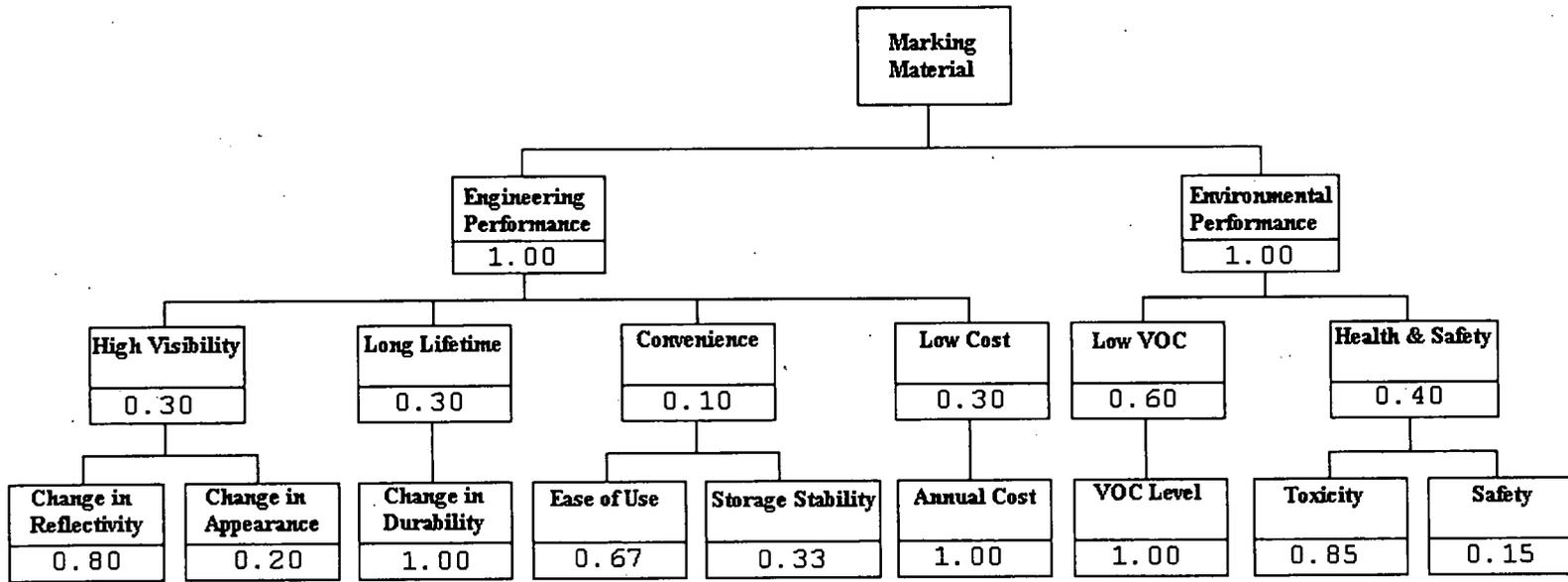
Figure 1. The relationship between the goals, attributes, and suggested (default) weights.

The environmental performance goals are expressed in terms of three attributes:

1. The VOC level (value of 0-1.25 lb per gallon);
2. The toxicity or the potential health hazard (value of Log V of 1-6); and
3. Safety rating (rating of 1-5).

Are These Equally Weighted in the Analysis?

Different weights are assigned to each of these attributes in the program. The weight reflects the importance of the corresponding attribute in the analysis. This weighting is to some extent subjective and can vary from location to location. The numbers shown in the Figure 1 are the weights suggested for different goals and attributes.

The software suggests a set of weights to be used in the initial analysis. However, these weights may not truly reflect the priorities of every user. PAMAS, therefore, allows users to revise these weights to better reflect their individual situations.

What Data Are Needed by PAMAS?

The program prompts the user to input nine values corresponding to measures of the nine attributes used in the analysis. These nine measures (described in full in the *NCHRP Report 392*) are as follows:

1. Estimated time in months for a stripe to loose its retro reflectivity to a value of 100 units. This is referred to as the T_{100} value;
2. Appearance of the stripe after 1 year of use, rated on a scale of 1-10;
3. Durability of the stripe after one year of use (Durability is measured as a tenth of the fraction of the marking remaining on pavement measured on a scale of 1-10;
4. Ease of application and removal of the marking rated on a scale of 1-5;
5. Storage stability rated on a scale of 1-5;
6. Annual cost of the marking (based on a 6-year period) in U.S. dollars;
7. The VOC content of the marking material measured in pounds per gallon. (Pounds per gallon is the common unit used in the industry--100 g/liter = 0.84 lb per gallon);
8. Toxicity value of the marking measured on a scale of 1-6; and
9. Safety of a marking material on a scale of 1-5.

Most users will NOT HAVE ALL THE DATA available to them. This, however, need not prevent them from using this methodology.

Note that measures 4 through 9 do not change appreciably with the geographic region where the marking is to be used. Most of these measures are very different for different classes of marking materials. Within a given class of marking material, however, they do not vary significantly.

NCHRP Report 392 includes the average values for these measures for six different classes of marking materials. These data are incorporated in the PAMAS program. The user may choose to use these "default" values in place of data not available for the candidate marking materials to be evaluated. To do so, the class of marking material of interest must be determined. The six classes along with the two-letter code for each class is given below.

Measures 1 through 3 will, in general, vary with the geographic location, and the user should ideally, provide the corresponding data. The program can substitute "default" values for these as well, but the user must appreciate that the default values available were obtained for quite different geographic locations. The resulting analysis will therefore only be approximate.

Solvent-borne paints	**SP**	Water-based paints	**WP**
Thermoplastic markings	**TP**	Epoxy markings	**EP**
Polyester markings	**PE**	Tape	**TA**

What Exactly Will the PAMAS Program Output?

The output from the PAMAS program is a plot similar to the one shown on Figure 2. Each data point on the plot refers to one of the marking materials evaluated. The horizontal scale indicates the engineering performance, while the vertical scale indicates the environmental performance of the marking material. Below the plot is a table showing the numerical values of engineering and environmental performance for each candidate marking material.

OPERATING INSTRUCTIONS

NOTE:

(a) It is not necessary to read the above introductory material to successfully run the PAMAS program. The software includes all information needed to run the program.

(b) There are two versions of the PAMAS program, one for Windows 95 users (labeled PAMAS95) and the other for Windows Version 3.1 users (labeled PAMAS31).

This is PC software; it will not run on Macintosh computers.

1. Copy the PAMAS program folder to the hard drive. The program will run faster on the hard drive.

   Copying can be conveniently carried out as follows: create a new folder named PAMAS on the hard drive. Load the disk into a drive. With the mouse, use the drag and drop features to drag the PAMAS folder from the disk into the newly created folder on the hard drive.

Environmental
Performance
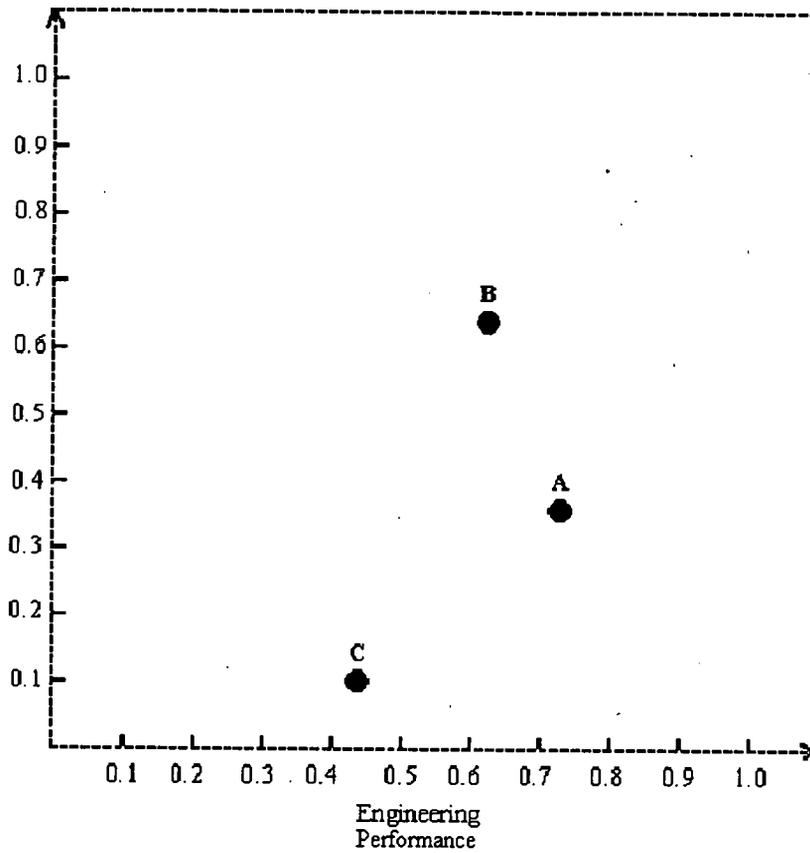
Code	A	B	C
U [Environmental]	0.36	0.65	0.10
U[Engineering]	0.72	0.62	0.44
T100 [months]	70.00	39.00	80.00
Appearance	9.10	5.00	7.40
Durability	10.00	9.00	4.00
Ease of Use	3.00	2.00	4.00
Storage Stability	2.00	3.00	2.00
Cost [$/year]	0.75	0.24	2.00
VOC [lbs/gal]	1.00	0.00	3.20
Toxicity	2.00	3.00	2.00
Safety	3.00	2.00	4.00
Category	EP	PE	SP

Figure 2. Performance analysis. (created using PAMAS version 1.0 [1997])

2. Double click on the PAMAS.exe file to open the program. The first screen (Screen 1) that comes up is an information screen. Press "**START**".

3. The second screen (Screen 2) gives summary information on the weights and how to change any or all of them. Press "**Next**" after reading the instructions.

4. Screen 3 shows the proposed hierarchical tree and the set of weights. This window needs to be maximized or made larger to view the entire tree diagram. There are two options at this stage: (a) to proceed with the proposed weights or (b) to change them.

--To proceed with the proposed weights (without any revision) press "**Accept**".

--To revise the weight of an attribute, click the **right mouse button** once on the specific attribute name (not the number) to be revised. Select "**Change Attribute value**" from the small pop-up menu that appears.

In the small pop-up window that appears, enter the new value of the attribute selected and press "**Set New Value**" button. Remember that the weights on a single "branch" of the tree must always add up to 1.00. When a single weight is changed, the program may alert the user to this fact and pop up a window showing the old weights and the revised weights of all attributes on the same branch of the tree.

If this is the case, the user will have to change the weights of the related attributes to obtain a sum of 1.00. The program cannot do this automatically because it has no information on how to revise the related weights. However, it will add the weights as they are entered so the user can check that the sum is 1.00.

After revising a weight, close the pop-up window by pressing "**Accept**". Press the "**Save**" button in the first pop-up window. Screen 3 will now be shown again with the revised weights in place. Press "**Accept**" again (using the button at the top or the bottom of screen) to proceed.

--To revise a weight at a higher level on the tree, double click the **right mouse button** on the specific goal or objective name (not the numbers). Enter the revised weight directly in the space.

5. The next screen (Screen 4) is an information screen that introduces the data input screen. Note the codes for different categories of marking materials listed on this screen.

Screen 5 will request nine pieces of data for each marking material to be evaluated. In most cases you will NOT have all the data needed to carry out the analysis. Therefore, default values have to be used in place of the missing data. These default values are taken from the NASHTO (and SASHTO) database and represent the average values reported for the respective measures in field tests.

Note the class of marking material the candidate marking material belongs to and its two-letter code. Press "**OK**" to proceed to the next screen.

6. The data is input into the program in Screen 5. On the top of the screen is a row of FIVE white boxes. The program allows up to five candidate marking materials to be evaluated simultaneously.

    Enter the first few letters of the name or a code for the first candidate marking material to be evaluated in the first white box on top of the screen. This will activate the column below it, presenting a row of 9 boxes in which to enter the data. The data needed are described to the left of the column.

    If the requested data are available, enter them in the appropriate spaces. The program will check the data to make sure that they fall within the minimum and maximum values shown. If they do not, the program will alert the user to this fact.

    It is possible to run the program even with NO data at all, relying solely on the default values based on SASHTO data.

    If ANY of the nine boxes are empty (i.e., no data available), it is necessary to enter the category of the marking material being evaluated in the last box on the column. Use the scroll bar on the box to select the appropriate category code.

Solvent-borne paints	**SP**	Water-based paints	**WP**
Thermoplastic markings	**TP**	Epoxy markings	**EP**
Polyester markings	**PE**	Tape	**TA**

    Press "**Accept**" to import default values into the column. The program will inform the user that default values are being used more than once, if more than one column is active. The input data may be changed even at this stage. Press "**Accept**" again to calculate and display the result.

    Warning: *The user must enter a sample name or code in the box at the top of the column even if the user has no data and relies entirely on default data. Merely selecting a category of marking in the last box and pressing "Accept" will result in a blank plot.*

7. The final result is a plot of the engineering performance versus the environmental performance of the marking materials of interest. These performance measures (or utilities) are not weighted. The numerical values for these quantities as well as the list of input data used to calculate them are listed in a table below the plot. Selecting the Print Preview option (from File) allows the complete plot and table to be viewed on a single screen. The plot and table can be printed selecting the "Print" command.

    Ideal marking materials with exceptional engineering performance as well as environmental performance will be located on the top right-hand corner of the plot. Marking materials located closer to this point on the plot are generally more desirable than those located to the left or lower

portion of the plot. In evaluating materials that yield data points placed very close to each other, the approximate nature of this analysis and the numerous assumptions made in its development must be kept in mind.

8. If the data points are closely located on the plot, a zoom feature is available in the title bar. Placing the cursor on the data point and pressing the **right mouse button** will display the input data used to calculate that data point. Press "Exit" to quit PAMAS.

9. An online Help feature is available in PAMAS and can be selected from the title bar.

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