Expert System for Diagnosing Hot-Mix Asphalt Segregation

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Asphalt pavement segregation is a continuing, costly problem in the paving industry. The problem is complicated by the many sources of segregation found in typical paving jobs. This paper reviews the origins and remedies of segregation, emphasizing the complex nature of the problem. Because of the complexity of the problem and its remedies, an expert-system solution, SEG, is proposed. SEG is a computer program founded on a knowledge base taken from the literature, combined with current expert input. The system interactively interviews the nonexpert user, who answers questions about the paving operation exhibiting segregation. On the basis of the user's replies, the system suggests changes in the operation to eliminate segregation. The system is rapid, simple, and portable—it can be used in the field with a lap-top computer. Expert systems hold great potential for changing the way transportation engineering problems are solved. The introduction of SEG as a practical tool for analysis is expected to help reduce segregation, and consequently improve pavement quality.

Random segregation of aggregate in asphalt pavements is a problem of much concern to the paving industry (*1,2*). Segregation of hot-mix asphalt (HMA) mixtures occurs when large aggregate sizes accumulate in one area of the paving mat while smaller ones accumulate in other areas of the mat. This effect leads to uneven distribution of density and asphalt contents in the mat, which can lead to premature distress in the pavement. Cracking, moisture-induced damage, raveling, and other durability-related damage may ensue. Pavement wear is increased by segregation (*3*). Moreover, segregation may reduce the extracted asphalt content in coarse areas, which may result in severe penalties for the pavement contractor (*4–6*). Consequently, it is important to identify conditions conducive to segregation and to transmit that knowledge to those responsible for the paving operation.

Because there are many sources of segregation, detecting the cause or causes on any particular job can be very difficult (*2*). A knowledge-based expert system is well suited to assist in the detection (*7,8*). Expert systems are a form of artificial intelligence, which can be used to help solve complex, nonnumerical problems (that is, problems that contain subjective elements). Expert systems have already found applications in civil engineering (*9*), with several applications in transportation (*9–12*).

This paper presents origins of and remedies for asphalt pavement segregation and then introduces an expert system, SEG, that captures that knowledge in a form that can easily and efficiently be presented to the field engineer. The expert system is a computer program that interviews the user and, based on the user's responses to queries from the program, suggests solutions to the segregation problem. In the past, the engineer needed to know the causes of segregation. With the help of the expert system, he need now only observe the various operations—the program will suggest the causes of segregation. Expert systems programs differ from conventional programming in that they use a heuristic set of rules and conclusions (which form the knowledge base) to make decisions.

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ORIGINS AND REMEDIES OF SEGREGATION

Random segregation of hot-mix asphalt can occur at any or all of several stages of the paving process—during mix design, mix production, transportation, or laydown operations. The problems associated with each are described below.

Mix Design

The mix design has a significant effect on segregation (*2, 13–15*). The best design is a well-graded aggregate that falls just above or below the maximum density line (A-line) shown in Figure 1, which is a plot of sieve size raised to the 0.45 power versus percent passing that sieve size on a linear scale. The slope of the A-line is determined from 100 divided by $M^{0.45}$, where M is the maximum-size aggregate in the mix. This line represents the particle-size distribution yielding the maximum density (minimum voids) for that maximum particle size (*16*). The maximum particle size is the sieve size on which no material is retained. Gradations in close proximity of this line are not likely to have enough void space to allow adequate asphalt coverage of the particles, resulting in a dry, friable mix. Preferable is a smooth curve lying just above or below the A-line. Such curves retain the well-graded characteristic needed to reduce segregation and provide sufficient void space for asphalt. Brock (*2*) suggests 2–4 percentage points above or below the A-line. Gradations above the A-line result in a finer mix, below the line in a coarser mix. Grain-size distribution curves that cross the A-line indicate gap grading—the absence of a range of particle sizes. Gap-graded curves are quite prone to segregation (*2*) because different aggregate sizes tend to interlock. If some sizes are missing, less interlocking occurs, and the particles are freer to move and segregate. Excessively large-size aggregate also accentuates segregation (*17,18*). The mix design engineer should be alert for segregation in any

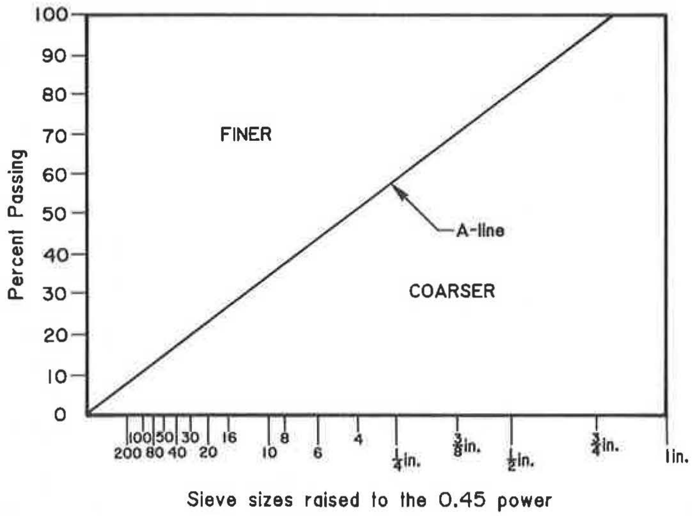

FIGURE 1 Gradation plot showing maximum density line (A-line).

mix, but special caution should be exercised for larger sized aggregate blends, which are used more and more now to minimize rutting potential.

The asphalt content also affects the segregation potential of the mix. Low asphalt content leads to segregation and high asphalt content deters it, since additional asphalt increases cohesion. Although increasing the asphalt content may be costly, penalties for placement of segregated pavements may be even more expensive. Brock (*2*) and Brock and May (*19*) suggest that changes in the asphalt content as small as 0.2 percent may significantly reduce segregation problems. When calculating asphalt content, mix designers should keep in mind the aggregate's absorptive capacity, which reduces the asphalt's ability to increase cohesion and reduce segregation.

Last, differing specific gravities of the aggregates can cause segregation. Particles with higher specific gravity are denser and tend to settle to the bottom, given the opportunity, during handling. Moreover, denser particles are more likely to roll when stockpiled, increasing segregation.

Mix Production

Segregation can occur at many different places in the asphalt mix production cycle. The operator must be alert for segregation at all the points described below, as well as at any facilities or operations peculiar to his plant. In general, segregation occurs when the aggregate is in motion.

Segregation may occur in the stockpiling operation (*2,13,15*). The aggregate may already be segregated when it is delivered to the HMA facility. If so, it must be integrated before asphalt is added. Batch plants do this with the screens above the hot-feed bins. Drums or continuous mix plants may require extra screening before such aggregate can be used. Segregation may also take place when the stockpile is created. The greatest segregation occurs when the material is placed in a large pile from a conveyor that throws the aggregate outward as it is placed. The larger the pile, the greater the amount of segregated large particles that accumulate around the base. The conveyor casts the larger particles a greater distance than it does the smaller ones, abetting segregation. Thus, if conveyor-fed stockpiles are used, a vertical chute ought to be added to the unloading end of the conveyor and stockpiles should be kept small. Still better would be to use a bulldozer to spread out the conveyor-deposited material into a large, flat area, thereby creating a layered structure. The conveyor would continue to deposit onto this structure while the bulldozer continued to spread the material out. Care should be taken not to push the material over the edge of the pile, which would allow larger particles to roll and segregate at the base. The slopes of the bulldozer-created pile should be less than the angle of repose of the aggregate.

Stockpiles may be created by end-dumping trucks. In general, the fewer times the aggregate is handled, and the shorter time it is handled and in free fall, the less the segregation will be (*15*). Trucks should discharge their loads as rapidly as possible; allowing the material to trickle or stream from the truck abets the segregation process. Trucks should minimize the height of fall of material by depositing each load to the side of the previous load, which will prevent large amounts of segregated material from accumulating from adjacent piles. (A larger pile can be created, if necessary, by bulldozing the smaller truckloads into a wedge-shaped pile. The bulldozer pushes the material up the wedge in successive layers, without shoving it over the back of the pile where it could roll and segregate (*2,20*). All slopes of this pile should be less than the angle of repose.)

All of the suggestions above apply to stockpiles of multiple-sized aggregate. Single-size aggregate does not segregate. However, care should be taken to prevent different sizes from mingling. Separately stockpiling different-sized aggregate is the safest way to deter segregation at this stage of the operation.

Segregation can be induced when the material is moved from the stockpile to cold-feed bins. The front-end loader should push the bucket directly into the pile rather than scooping up along the face of the pile (*15*), which would likely gather just larger particles in the bucket. With drum plants, it is especially important to ensure that the bin-loading procedure preserve the gradation that the mix design was based on. The cold-feed bins should be loaded by vertically dropping the material into the center of the bins. Placing the material against the sides of the bin or adding a horizontal component of trajectory increases segregation. Again, the more quickly the material is placed, the less chance of segregation.

Details of bin construction can reduce the potential for segregation. If bins are adjacent, vertical barriers between the top of the bins serve to keep material from spilling out of one into another. Kennedy et al. (*15*) and Brock (*2*) recommend that the bin discharge opening be trapezoidal rather than rectangular. If the wide end of the trapezoid is in the downstream edge of the opening, the material will flow more freely from all areas of the bins. Otherwise the material tends to discharge solely from the center, inducing segregation on the edges. The trapezoidal shape helps keep the aggregate from arching over the discharge opening.

Certain details of batch plants must be observed. The screens above the hot-feed bins must be kept in good repair. Holes in the screens will lead to an improper mix, which may segregate easily. The finest sized bin is most likely to develop segregation because it has the largest range of sizes—often a few orders of magnitude.

Material must be placed in the middle of the bin rather than along the side, as often happens. A baffleplate placed below the screens can direct the falling material from the edge of the bin into the center. This is especially important if the fines from the baghouse are returned here. Since the fines pass through the screens almost immediately, they accumulate on one side of the bin. Moreover, they may attach themselves to the side of the bin and later fall off in large chunks. A vibrating plate on the bin wall eliminates the latter problem, and a baffleplate attached to the side reduces the former (*2*). Adding a baffleplate may reduce bin capacity, but the benefits of doing so may well offset this disadvantage.

Particular components of continuous mix plants can contribute to segregation. Since sufficient asphalt content is an important parameter in reducing segregation, it is important that the aggregate stay in the drum mixer long enough to become coated with asphalt. If this is not occurring, several corrections are possible: introduce more asphalt, add the asphalt to the drum sooner, or increase the mixing time in the drum. Mix time can be increased by kickback flights in the drum, dams, or longer drum length. The increased time in the drum, however, also drives off more moisture, which Rice (*21*) indicated aids in segregation.

As the material rotates in the drum, it tends to segregate, with the coarser particles staying on the bottom of the drum and the finer particles going higher up the sides. As the material exits the rotating drum, the coarser material tends to fall to one side of the conveyor and the finer material to the other (*2*). If the discharge conveyor is parallel to the discharge direction, segregation is accentuated as the coarse material consistently accumulates on one side of the conveyor. This one-sided segregation is carried through the other plant operations and eventually manifests itself as a stripe of segregated pavement. However, if the discharge conveyor is perpendicular to the discharge direction, this effect is mitigated since the material is spent out evenly over the conveyor.

After the asphalt is mixed with the aggregate, it is either discharged to a truck or to a storage silo. The storage silo operation presents several opportunities for segregation. When the mix leaves the mixer, it is transported to the storage silo, usually by a drag conveyor. As Higgins (*18*) notes, drag conveyors are superior to screw augers, skips, or hoists in this phase of the operation. However, if the face of the drag conveyor is cool, fine parts of the mix may adhere to the surface, causing the drags to hydroplane, which in turn allows the coarser particles to skim over the tops of the drags, increasing segregation (*2*). In this situation, the conveyor should be equipped with heated bottoms and floating hold-downs (idler wheels) to eliminate the problem. This problem is particularly exacerbated at start-up. If the drag conveyor is running much faster than the mix is being produced, the drags will not be full, which leads to segregation because the particles can move around (*14*). Similarly, if the conveyor is running too slowly, the drags may become overloaded and overflow as the material is taken up towards the silo. This condition, too, leads to segregation, with the larger particles rolling back down the conveyor. Care should be taken to match the bin-batcher opening rate with the drag conveyor speed; if the batcher delays opening, it overflows, causing the mix to spill down the conveyor (*2*). The mix segregates when this happens.

The mix must be placed properly in the storage silo to avoid segregation. Rather than place the mix directly from the drag conveyor into the silo, the mix placement should be buffered by either a bin batcher (*5,18*) or a rotating chute (*15*). The bin batcher, which should hold at least 4,000 lb of mix (*2,13*), is simply a bin above the storage silo. The batcher is placed above the storage silo, and it is filled by the drag conveyor. After the batcher is filled, it should be emptied in one quick motion. The plug of mix should fall into the storage silo and splatter over the mix already there (*18*). The batcher should be emptied only when it is full, not on some arbitrarily decided time schedule. The batcher doors must be closed before all the mix has exited, lest any mix from the drag conveyor be placed directly in the storage silo. The height of fall into the storage silo should be sufficient that the material splatters on impact. Thus, the silo must not be kept too full or the splatter effect will be foiled. Similarly, if only small amounts are discharged from the batcher, there may not be enough redistribution of the material on impact (*13,15*). The bin batcher should be loaded by a vertical fall of the mix from the drag conveyor (*13*), because a horizontal trajectory would lead to segregation.

A rotating chute at the top of the storage silo may be used in lieu of the bin batcher to reduce segregation (*2,15*). The chute's effect is twofold. Primarily, the mix is distributed around the interior of the silo rather than landing in a pile in the center where larger particles may fall to the edges. Moreover, the properly operating chute directs the material straight down so that it does not land on the silo wall, producing segregation when some particles rebound more than others.

Other devices have been used to minimize storage-silo segregation. Middleton et al. (*6*) describe a horizontal, rotating-screw auger arrangement that fits on top of the storage silo, raining the material into the silo in a sheet instead of a stream. Foster (*5*) reports a storage silo with a pugmill on top. The pugmill removes the effects of previous segregation by mixing. The mix then dumps into a series of splitting hoppers before coming to rest in the silo. Kennedy et al. (*22*) note that while this method reduces segregation, it does not always eliminate it. Using an inverted (upward-pointing) cone in the silo exit causes some remixing as the mix departs, reducing segregation (*5*).

The storage silo details are important. The discharge-end of the silo should be a steep cone (greater than 55 degrees (*15*)) so that the material is pulled evenly from the bin and not just from the center. If the sides of the cone are not steep enough, an inverted cone forms in the mix as the silo empties and the aggregate segregates as it rolls down the center of the inverted cone (*14*). The silo cone should be insulated to improve the smoothness of the mix flow from the bin (*13*). Although it appears that the discharge-gate details are not extremely influential, the gates should be large enough so that the material does not stream out but instead emerges as a large mass (*2,14*).

The silo may be emptied entirely with little effect on segregation if the mix is well graded (*2,19*). However, as Kennedy et al. (*15*) recommend, the silo should be filled above the top of the cone at all times when using gap-graded mixes.

Transportation

Segregation can take place when the mix is transported from the HMA facility to the job site. Truck loading and unloading are the primary problem times. Trucks should be loaded with three small deposits rather than one large one (*2*). The truck bed's front, rear, and middle should receive separate loadings, in that order, to reduce the size of the piles and overall segregation (*14*). Moreover, segregation is further reduced because the length of the front and rear piles is reduced and particles cannot roll as far as they could if they were in one pile. This is especially important in reducing the end-of-load/beginning-of-load segregation overlap that occurs when the trucks discharge into the paver.

The location of the piston that raises the truck bed can cause segregation. If the piston intrudes upon the bed, typically at the front of the bed, the asphalt mix may segregate when it falls into the cavity left by the piston well when the truck is unloaded. The solution is to block off the parts of the bed adjacent to the well so that no cavity is formed when the mix exits the truck bed.

Rough or bumpy truck beds assist segregation. Beds should be kept smooth and clean so that the mix slides instead of rolls out, which enhances segregation. Last, the mix should be deposited in the paver in a deluge. Hensley (*14*) and Kennedy et al. (*15*) recommend raising the truck bed before opening the tailgate to make the mix move faster and aid in deluging the paver hopper. The rapid movement reduces segregation at the start of the dumping operation.

Laydown Operation

Segregation can be caused by incorrect operation of the paver. The variables affecting segregation in the paver are:

- Operation of the paver wings,
- Speed of drag slats,
- Paver throat opening, and
- Auger condition and speed.

Perhaps the most common cause of segregation in paving operations is the periodic emptying of the paver wings into the paver. If the hopper is allowed to empty, some coarser material will accumulate in the wings, and when they are dumped, a lateral band of segregated material is laid down. This problem can be moderated if the hopper is not allowed to become less than one-quarter empty (*14,15*).

Keeping the hopper at least partially full has other advantages. The drag slats should not be starved for mix, or they will segregate the mix. If the augers are starved for mix (because of small throat openings, slow drag slats, or absence of mix in the hopper), segregation will occur (*14*). The throat openings in the paver should be kept wide open (*2,14,22*). Restricting the flow from the hopper to the auger can result in starving the auger for mix, which causes the larger particles to move to the outside of the mat, leading to segregation at the edges of the mat. Therefore, it is important to keep the throats wide open and to adjust the speed of the auger to keep the mix spread the full width of the paver.

The same effect results if the auger speed is too fast for the amount of mix being sent to the auger. The larger particles are thrown to the outside, yielding side-to-side segregation. If the auger speed is too slow for the amount of mix going to it, the outside edges of the paving mat exhibit segregation (*14,15*).

The auger must be kept in good condition. Larger particles may congregate wherever the auger is worn or broken. Reverse baffles should be placed at the center of the auger to push the mix under the center of the auger gearbox. If the reverse baffles are not working properly, coarse material will accumulate, causing linear segregation in the center of the mat.

Finally, after the mat has been laid, some careful manual finishing operation must be done to join the mat to an adjacent mat. The mix should be placed over the joint carefully, and not scattered across the pavement, for higher joint density and less segregation. Generally, curtailing manual work results in higher quality pavement (*15*).

EXPERT SYSTEM

An expert system, SEG, which incorporates the information on segregation discussed above, was constructed to aid hot-mix industry personnel in attenuating random segregation problems. The expert system is not a conventional computer program with a specific algorithm for solving problems. Rather, it uses a knowledge-based processor (an inference engine) to determine when to apply the expert knowledge contained in the program. SEG is an interactive microcomputer-based program that gathers information from the program user. The user-provided information is compared to information in the program, resulting in suggestions on possible sources of segregation. The program requires a personal computer, either a conventional desktop or a portable lap-top machine. The portability of a lap-top model may especially suit it for field evaluations.

SEG has the potential to reach several conclusions, based on user input. The general categories of conclusions for SEG are as follows:

- There is a problem with the mix design.
- There is a problem with the stockpiling operation.
- There is a problem in the HMA plant per se.
- There is a problem in transporting the mix.
- There is a problem in the laydown operation.

Within each of these statements are more specific sublevels that help pinpoint sources of segregation and recommend remedies. SEG does not stop once a source of segregation is found; it continues to delve until enough information is gathered to make a decision in all the areas outlined above.

In order to implement the system, the user must be able to recognize both random segregation in the completed mat and segregation of the mix at various points in the HMA plant. He must have knowledge of plant machinery and be able to visually inspect the aggregate and the mix at different locations in the operation. The program will ask the user what plant type is in operation and the details of particular equipment, including the storage silo, the conveyor leading to the silo, the hot-mix bins, and truck and paver. Depending on the user responses, the expert system continues to ask questions and display possible solutions to the problem. Because it is unlikely that the segregation problem has only one source, the program continues to interview the user until all sources of random segregation have been investigated.

Knowledge Base

The information in the program on sources of segregation represents the knowledge of the experts. This information forms what is called the knowledge base of the program. For this study, the knowledge base was taken from the literature (*2,5,6,13–15,19–21*) and experts at the National Center for Asphalt Technology. The knowledge is entered in the program in a series of logical rules:

IF a certain condition exists (is true)
THEN a certain conclusion is reached
AND some action is initiated.

The action initiated is either the reaching of a conclusion with attendant suggestions for improving the operation or the firing of another rule to gather more information from the user. These rules are networked so that each rule leads to the execution of another rule and/or the display of a conclusion. The results of one rule are remembered by the program and lead to the selection of the next rule to be executed. The order of succession of the rules reflects the thought process of the experts used to analyze the problem. The rules are entered into the knowledge base in the English language, making programming relatively easy.

The general structure of the knowledge base is shown in Figure 2. Figure 3 shows the broad rules corresponding to Figure 2. The RULE statement indicates the topic that the rule concerns. The IF statement is the true/false question that the program asks the user. If the user replies *true*, then the THEN statement is executed, as well as any AND statements

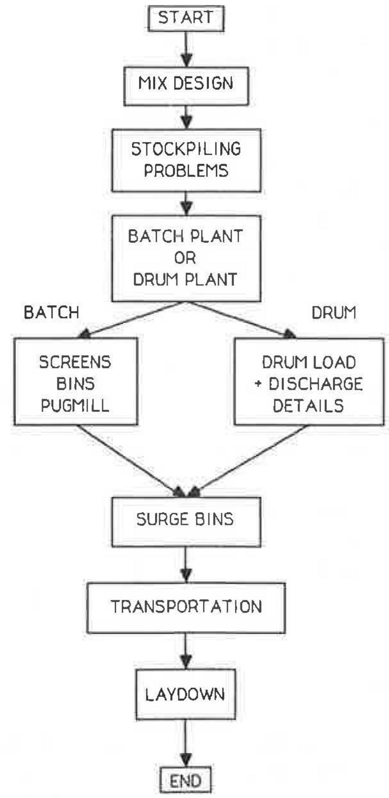

FIGURE 2 General structure of the knowledge base of SEG.

that follow. If the user replies *false*, the THEN statement is not fired, and the program proceeds to the ELSE statement. DISPLAY statements indicate that the program will give suggestions on how to attenuate the problem at hand. The CHAIN statements indicate that the program will branch to another set of subrules or conclusions before returning to the main rules shown in Figure 3.

Program Operation

Expert system operation is straightforward. The program asks the user a series of true/false questions about the particular hot-mix production/transportation/laydown cycle. A sample question is as follows:

Is it true that the cold-feed bin is allowed to empty entirely?
True *False*

This simple true/false format was chosen over more complex interfaces because it fits the problem and because the conclusion had to be found quickly. Most segregation problems are encountered only after the paving operation is under way, making rapid solution of the problem a high priority. While the user needs to understand the question, he need not understand the *significance* of the question (that is, he need not be an expert). However, the program does understand significance and it explains what problems may arise from allowing the cold-feed bin to empty entirely. Herein lies the usefulness of the expert system—an untrained observer can give his

RULE Check material for gap-grading.
IF The material as received was gap graded.
THEN DISPLAY gapgrade
AND CHAIN agmixtype.prl
ELSE CHAIN agmixtype.prl

RULE Check if a single mix being used.
IF Is a single mix type being used.
THEN CHAIN pileseg.prl
ELSE CHAIN surgebin.prl

RULE Check if operation is a batch or drum plant.
IF Are you operating a batch plant?
THEN CHAIN batch.prl
ELSE CHAIN drum.prl

RULE Check if mix is segregating in the surge bin.
IF Is the mix segregating in the surge bin?
THEN DISPLAY surgebin
AND CHAIN full-empty.prl
ELSE CHAIN hydroplane.prl

RULE Check if transportation is causing segregation.
IF Is the mix unloaded by the truck segregated.
THEN DISPLAY trucking
AND CHAIN laydown.prl
ELSE CHAIN drum.prl

RULE Check if paver is causing segregation.
IF Is the mat segregated.
THEN DISPLAY paver

END

FIGURE 3 General rules for inference network shown in Figure 2.

response to the system and receive the significance of his observations from the knowledge base in the program: The computer becomes the "expert," based on the expertise incorporated into the knowledge base; the personnel responsible for the hot-mix job need not have an expert on hand to interpret the observations for him—the expert system does it, based on user observations and responses to program queries.

SEG was written using the expert system shell program INSIGHT2+ (*23*). The shell provides a language and compiler that allow the creation of rules that constitute the knowledge about segregation. The compiler provides for an orderly execution of the rules so that the user progresses through the knowledge base in systematic fashion. For example, if the user replies TRUE to the query on whether he is running a batch operation (as opposed to a continuous operation), the program ceases to make inquiries related solely to continuous operations. The shell thus provides an efficient way to search the knowledge base. SEG was written on an IBM personal computer and operates on PC-compatibles.

The information stored in the program is called a knowledge base, which is a set of rules consisting of questions asked of the user followed by branching statements based on the user's responses. The branches lead to conclusions about where segregation may be occurring in the operation and to suggested cures. Some of the rules contain information explaining the significance of the question, as well as information on the potential for segregation based on the reply to the question.

For example, the user might be asked if the cold-feed bins are adjacent (*true/false*). If they are adjacent (*true*), the program generates the following display before branching to the next rule:

> *Segregation can originate in the mixing of different size aggregates in the cold feed bins. Since the bins are adjacent, check to be sure that the aggregates are not spilling over from one bin to another. If so, provide bin dividers to prevent mixing. Instruct loader operator to be careful not to mix sizes.*

The display can be sent to the printer to create a permanent record of the session. Given the arrangement of rules, the program can reach many different conclusions before the session is completed by chaining together several knowledge bases (each with its own conclusions). The program, having reached one conclusion, proceeds to the next knowledge base rather than ending the session with the first conclusion reached. Chaining also allows a very large number of rules to be incorporated into the program, limited only by the extent of the computer memory.

One of the advantages of an expert system is its ability to quickly enact several scenarios to test the effect of different plant changes on segregation. A typical session with SEG takes less than 15 min, allowing the user to make different trials quickly. Moreover, the trials could be run *before* job operation begins to locate potential causes of segregation.

Sample SEG Run

A sample run of SEG is presented to illustrate the system's application. The system gathers information from the user until it has sufficient data to indicate where segregation may be occurring in the HMA operation. When starting the system, the user is asked first about the mix design [the most likely parameter causing segregation (*2,15*)]:

> *Is it true that the material, as received, was gap-graded?*
> *True* *False*

If the user is unsure of the term "gap-graded," he may obtain further explanation by invoking the EXTEND function, which generates the following message:

> *A material is "gap-graded" if some sizes of aggregate are missing from the aggregate.*

If the user answers TRUE, the program generates the following information:

> *If the material is "gap-graded," i.e., some sizes of aggregate are missing from the aggregate, segregation could be occurring in the source pile of aggregate. Gap-graded grain size distribution curves have a stair-step appearance. The best cure is to blend sizes of aggregate to fill in the gaps. When grain sizes are plotted on the 0.45 power plot, the grain size distribution should lie slightly above or below the maximum density line (A-line), but never cross it.*

The system then gathers information on aggregate handling.

First, to determine whether the aggregate is becoming segregated in the stockpiling operation:

Is it true that the material is segregating in the stockpile?

True *False*

If true, remedies are presented to the user. To determine and explain problems in cold-feed bin operation, the program continues by asking:

Is it true that the material is segregating in the cold feed bin?

True *False*

At this point, the program follows different lines of inquiry depending on the type of plant. Until this point, the features of both batch and drum plants have been about the same. The user is asked next whether he is analyzing a batch or drum plant. The following question is:

Is it true that the mix is completely coated with asphalt?

True *False*

If the user had responded earlier that a drum plant was being analyzed, the remedies offered would be:

Low-asphalt content aids segregation. If the mix is not well coated, consider these improvements:

1. Increasing time in drum mixer by

- *Decreasing slope of the drum,*
- *Putting kickback flights in the drum,*
- *Putting a dam in the drum.*

2. Moving the asphalt nozzle further into the drum.
3. Increasing the asphalt content.

Had it been a batch operation, the reply would be:

If the mix is not coated completely, consider the following changes:

- *Increase mixing time in the pugmill.*
- *Inspect the tips and shanks of the mixer for wear.*
- *Increase the asphalt content.*

Next, the operation of the drag conveyor at the drum exit is examined.

Is it true that the drag conveyor is perpendicular to the drum exit?

True *False*

Is it true that the drag conveyor to the surge bin is hydroplaning?

True *False*

These questions, if answered affirmatively, generate displays that show the user the proper orientation of the drag conveyor to the drum. If hydroplaning is a problem, two possible remedies are suggested.

Hydroplaning results in segregation as the smaller particles accumulate on the conveyor and pass under the drags, leaving the coarser mix to travel up the conveyor.

Two solutions are available:

1. Heat (or increase the heat on) the drag conveyor to reduce the possibility of asphalt accumulating on the conveyor.
2. Equip the drag with floating hold-downs.

The surge (or storage) silo is examined next. The first question determines whether there is a silo, and, if so, whether it might be causing a problem:

Is it true that there could be segregation occurring in the surge silo?

True *False*

If there is a surge silo, the system examines whether the fall of the mix from the drag conveyor into the bin is buffered. The details of the buffer device, whether it is a bin batcher or a rotating chute, are reviewed.

The last two parts of the system go over the trucking and paving operations. The program asks the user how trucks are loaded and unloaded, emphasizing the need to load the truck in several small batches rather than in one big one. If the user notes that unsegregated truck mix is segregated after it is placed in the paver bin, the following advice is given:

The truck should flood the paver bin with hot mix. Do not allow the mix to be dribbled into the bin through an opening in the tailgate or through the tailgate itself.

Tip the bed of the truck up before opening the tailgate to assist in the flooding of the paver bin.

If the truck bed has a well at the front for a hydraulic piston to lift the bed, beware of segregation around the cavity in the mix left by the piston well as the mix slides off the bed. Block off the parts of the bed adjacent to the well so that no cavity is formed as the mix exits the truck bed.

Truck beds should be kept smooth and clean so that the mix slides out rather than exits with any rolling action, which enhances segregation.

Last, the paver is examined. The system queries:

Is it true that unsegregated mix is coming out segregated from the paver?

True *False*

If the answer is *true*, the ensuing text is shown.

Check the following items:

- *Drag slats are covered with mix at all times (bin is always at least 25 percent full).*
- *Throat openings are wide open at all times.*
- *Auger is not broken or worn.*
- *Auger speed matches slat speed, so mix is not slung to the sides (too fast) or mix is not driven to the ends of the auger (too slow).*
- *Asphalt content is not too low.*

- *Paver wings are being emptied.*
- *Auger gearbox baffles are in good repair.*
- *Manual dressing of the joint is done properly (pack the mix in the joint—don't cast it over the mat).*

Thus SEG completes the survey of the HMA facility, transportation, and laydown operations. The user can then either go through another session with SEG or exit the system. Simply by recognizing segregation, the user can run the expert system and receive all the information he needs to remedy the problems causing segregation.

CONCLUSIONS

Asphalt pavement segregation is a continuing, costly problem in the paving industry. Segregation's manifold sources further compound the problem—no single procedure will eliminate all instances of segregation. This study reviewed segregation's origins and remedies, emphasizing the complex nature of the problem.

Because the problem and its possible remedies are so complex, an expert system solution has been proposed. The expert system, SEG, was created with the shell program INSIGHT2+; SEG's knowledge base is taken from the literature, combined with current expert input. The system interactively interviews the nonexpert user, who answers questions about the paving operation exhibiting segregation. Based on the user's replies, the system suggests changes in the operation to eliminate segregation. The system is rapid, simple to use, and lends itself to field application with a portable lap-top computer.

Expert systems are a new technology with great potential for changing the way transportation engineering problems are solved. The emergence of expert systems in engineering is relatively recent, even though these systems have already found routine application in such diverse fields as health care and computer system selection (*8*). The introduction of SEG as a practical tool for analysis is expected to aid in the reduction of segregation. The knowledge base and further updates for SEG are available from the author.

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