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Committee of State
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DRAFT TRH21: 1996

HOT MIX RECYCLING

TECHNICAL RECOMMENDATIONS
FOR HIGHWAYS

DRAFT TRH 21

HOT MIX RECYCLING

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PREFACE

TECHNICAL RECOMMENDATIONS FOR HIGHWAYS (TRH) are written for the practising engineer and describe current recommended practice in selected aspects of highway engineering. They are based on South African experience and the results of research and have the full support and approval of the Committee of State Road Authorities (CSRA).

To confirm their validity in practice, TRHs are circulated in draft form for a period of trial before final approval. This document, Draft TRH21, will therefore be in use for a limited period during which you are welcome to send suggestions for improvement to

The Director General,
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P O Box 415,
Pretoria,
0001

Eventually a revised document will be issued as a full TRH.

SYNOPSIS

Hot mix recycling is widely accepted as a viable road rehabilitation option. Since 1981, a number of major rehabilitation projects using hot mix recycling have been completed.

The successful undertaking of hot mix recycling depends on how well various distinct aspects are addressed. These would include technical and economic feasibility investigations, plant requirements, design methodology, construction techniques and contractual procedures.

This document examines the relevant parameters that need to be taken into account in the feasibility, design and implementation phases of hot mix recycling. It provides guidelines and recommendations covering each phase.

SINOPSISIS

Warmmenghersiklering word wyd as 'n lewensvatbare padvernuwingsopsie aanvaar. Sedert 1981 is 'n aantal belangrike vernuwingsprojekte voltooi waar daar van warmmenghersiklering gebruik gemaak is.

Die suksesvolle onderneming van warmmenghersiklering hang af van hoe goed verskeie afsonderlike aspekte aangespreek word. Dié sal tegniese - en ekonomiese - uitvoerbaarheidstudies, aanlegvereistes, ontwerpmetodologie, konstruksietegnieke en kontraktuele prosedures insluit.

Die dokument ondersoek die toepaslike parameters wat in die lewensvatbaarheid-, ontwerp- en uitvoeringfases van warmmenghersiklering in aanmerking geneem moet word. Riglyne en aanbevelings wat elke fase dek, word verskaf.

GLOSSARY

Cold milling - A controlled pavement removal process that performs tailored, full or partial depth removal and profiling of an asphalt pavement, by a machine equipped with a rotary cutting drum. No preheating is necessary.

Cold mix recycling - The process in which reclaimed asphalt is combined with new binder and/or recycling additives in place, or at a central plant, to produce cold-mix base mixtures.

Hot mix recycling - The process in which reclaimed asphalt is combined with new aggregate, new binder and/or recycling additives in a central plant to produce a recycled hot asphalt mix which satisfies standard specifications.

Hot surface recycling - The process in which an asphalt pavement surface is heated in place, milled or scarified, remixed, relaid and rolled. New binder, recycling additives, new asphalt, new aggregate, or combinations of these may be added to obtain desirable mix characteristics.

Reclaimed asphalt/material - Old asphalt reclaimed for recycling by either cold milling or ripping, breaking and crushing.

Reclaiming techniques - Techniques used to recover existing asphalt pavement material from a road and the processing of this material to make it suitable for reuse through the hot mix recycling process.

Removed material - Old asphalt to be disposed of, ie material which is not to be used for recycling purposes.

Ripping and crushing - The loosening and breaking-up of an in situ asphalt layer by means of tines or some type of impact technique, and the subsequent crushing of the material at a central plant to a prescribed grading envelope.

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1 INTRODUCTION

Hot mix recycling, that is the reuse of existing asphaltic pavement materials, is accepted in South Africa, as in the rest of the world, as a viable road rehabilitation and maintenance option. Over the last 15 years it has been used successfully on many rehabilitation projects internationally.

Many reasons have been put forward for pursuing hot mix recycling. These include the following:

- increasing costs of pavement materials
- shortages of quality aggregates in some areas
- haulage costs of new material
- ecological concern regarding new quarries and the conservation of natural resources
- energy conservation
- geometric limitations of existing roads

The conservation of energy and natural resources is an important consideration and road authorities may well decide, in national interest, to use hot mix recycling in certain cases even though it may be more expensive than alternative rehabilitation options. However, over the long term, the road industry will only use hot mix recycling to the full if it is more economical than alternative options.

Pavement materials have been re-used in South Africa for many years, long before the term "recycling" came into general use. However, in general, the methods employed entailed the re-use of material at ambient temperatures. Hot mix recycling was relatively untried until 1981 when the undertaking of the Van Reenen's Pass road rehabilitation project focused considerable attention on the process. Since then, hot mix recycling has been used on a number of major projects and by various asphalt producers. It has also been the subject of much research in the country, including Heavy Vehicle Simulator (HVS) testing.

A Technical Working Group on Recycling was formed under the auspices of the CSIR in 1984 to optimise recycling practice in the country. The purpose of this Group was to realise the full potential of the recycling process through debate and discussion, by contributing to current research, and identifying needs for further research, development and implementation. The Group has included representatives from national, provincial and local road authorities, researchers, consultants, contractors, and plant manufacturers.

It has greatly stimulated the advancement of the recycling practice of bituminous pavement material in South Africa. Issues such as mix quality, economic advantages, specifications, contractual procedures and plant requirements have been critically examined and effectively addressed. Consensus has been reached in many areas and feedback from this Group has proved to be valuable in terms of both current and projected research activities.

The work of the Group has led to the following series of documents detailing guidelines for the process:

- "Hot mix recycling: technical considerations prior to implementation" (1)
- "Hot mix recycling: mix design procedure" (2)
- "Hot mix recycling: economic considerations" (3)
- "Hot mix recycling: reclaiming and stockpiling techniques" (4)
- "Hot mix recycling: plant requirements" (5)
- "Hot mix recycling: contractual procedures and specification guidelines" (6)

The above documents have provided a valuable contribution in the compilation of Draft TRH21, which is aimed at providing guidelines and recommendations covering the feasibility, design and implementation phases of hot mix recycling.

2 PAVEMENT MATERIAL RECYCLING

In general the conventional methods of rehabilitating flexible pavements involve resurfacing, milling of surfacings and replacing them with new material, and reconstruction. With these processes the existing material is either replaced or covered with additional new material.

Recycling embraces the technology which aims to reclaim material from the existing pavement, upgrade it with the addition of supplementary materials and use the final product as an improved structural material.

Pavement material recycling can be a hot or cold operation and the process can either be done in-place or the reclaimed material can be transported to a central plant for reprocessing. The reclaimed material can also be stockpiled for future use. Various types of recycling have been practised in many countries for quite some time.

With regards to bituminous pavement materials, there are three broad categories of recycling:

Cold mix recycling - The process in which reclaimed asphalt is combined with new binder and/or recycling additives in place, or at a central plant, to produce cold-mix base mixtures.

Hot surface recycling (eg remixing, repaving) - The process in which an asphalt pavement surface is heated in place, scarified (or milled), remixed, relaid and rolled. New binder, recycling additives, new asphalt, new aggregate, or combinations of these may be added to obtain desirable mix characteristics.

Hot mix recycling - The process in which reclaimed asphalt is combined with new aggregate, new binder and/or recycling additives in a central plant to produce a recycled asphalt mix which can satisfy standard specifications.

This document deals with the last category of pavement material recycling.

3 THE HOT MIX RECYCLING PROCESS

The process of hot mix recycling basically entails the following:

- reclaiming, hauling and stockpiling existing bituminous material
- reprocessing of reclaimed material in a central plant
- using the resultant mix in the construction of pavement layers

The success of the process depends *inter alia* on the availability of recycling plant with the ability to:

- produce the specified mix
- process a variety of combinations of reclaimed and new materials
- conform to environmental regulations
- operate at acceptable productivity levels
- switch easily from recycling to conventional operations and vice versa

These requirements have been met successfully using modified mixing plant of both the batch and drum-mixer types. These modifications range from simple additions to existing plant to highly complex equipment specially manufactured for this purpose.

The degree of complexity of a plant is directly related to its ability to economically produce mixes containing high proportions of reclaimed material and conforming to environmental regulations. However, a high proportion of reclaimed material and thus complex plant is not a prerequisite for economic recycling. In fact a modest proportion of old material will frequently be preferable when considering grading requirements or the availability of reclaimed material. A producer can therefore choose to recycle and meet all the requirements without having to invest in complex plant modifications or new plant. On the other hand, the higher proportions of reclaimed materials that are possible with modified drum-mixers have the potential for greater economies.

Other factors that need to be taken into account for the successful undertaking of hot mix recycling include reclaiming plant and methodology, stockpiling techniques, mix design and quality control. These factors are addressed in this document. The use of the resultant mix is not different from conventional paving practices and therefore it does not require special consideration.

4 FEASIBILITY INVESTIGATIONS

4.1 PAVEMENT REHABILITATION — THE GENERAL APPROACH

A general procedure for the flexible pavement rehabilitation design process is given in Draft TRH12 (7). With regard to hot mix recycling, some additional factors have to be taken into account (1). These include the following:

- the size of the project
- the value and quality of the existing material
- new material requirements and haulage distances
- the availability of equipment and expertise
- logistics

A simplified flow diagram of the rehabilitation design process for hot mix recycling is given in Figure 1. The determination of the technical and economic feasibility of the hot mix recycling option is discussed in detail in the following sections.

4.2 TECHNICAL FEASIBILITY

The following three-step procedure (see Figure 2) is recommended for the determination of the technical feasibility for hot mix recycling:

- An initial determination of sections of distressed pavement which may be suitable for recycling.
- A material variability assessment of sections deemed suitable for recycling.
- Preliminary mix design; that is, the determination of whether the existing asphalt can be recycled to produce a resultant mix with properties similar to that of a conventional mix.

4.2.1 Initial assessment

The aim of this phase is to identify sections of the road which may be suitable for hot mix recycling. The investigation should follow the approach outlined in Draft TRH12 (7) and shown in Figure 3. The road is divided into sections exhibiting:

- no significant distress
- surfacing distress only
- localised factors causing distress
- extensive structural distress

Hot mix recycling may be an appropriate option for the last three cases.

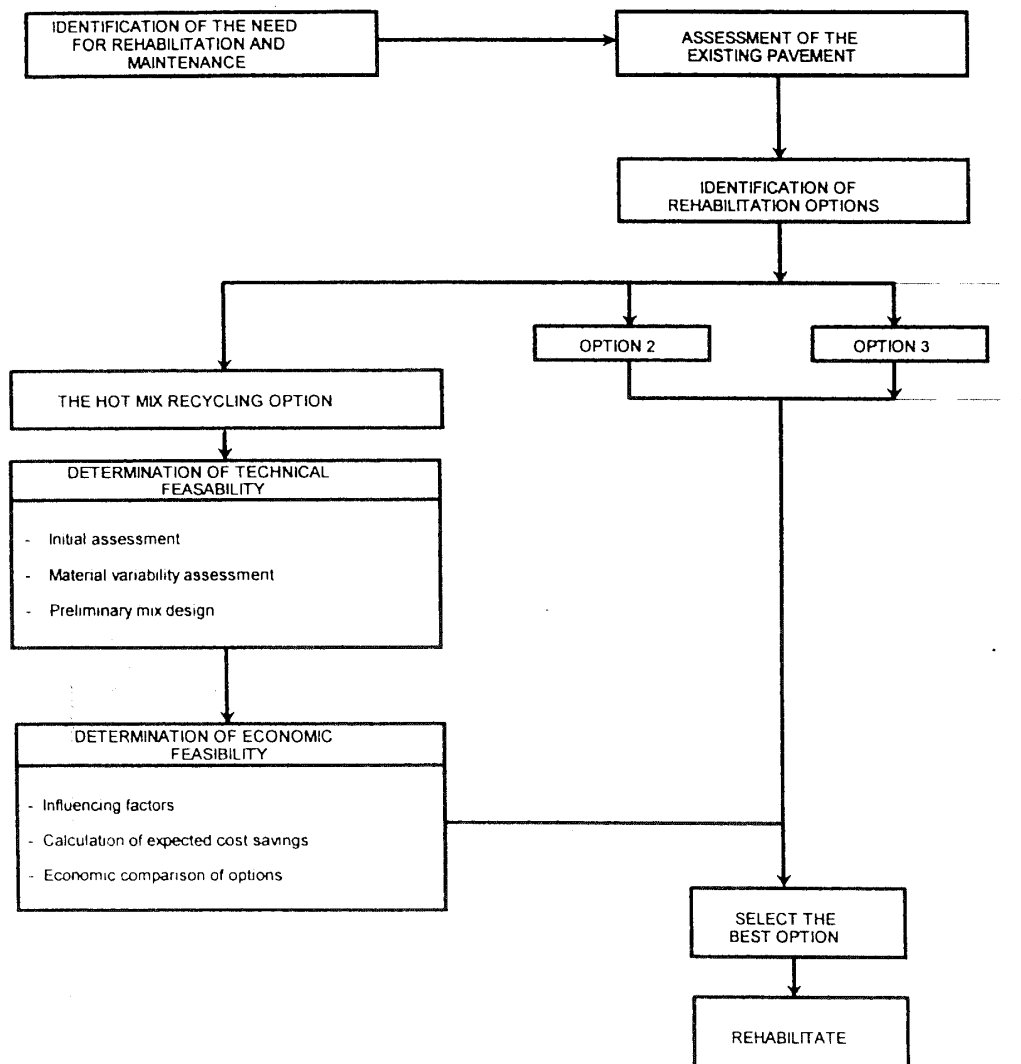


FIGURE 1: REHABILITATION DESIGN PROCESS FOR HOT MIX RECYCLING

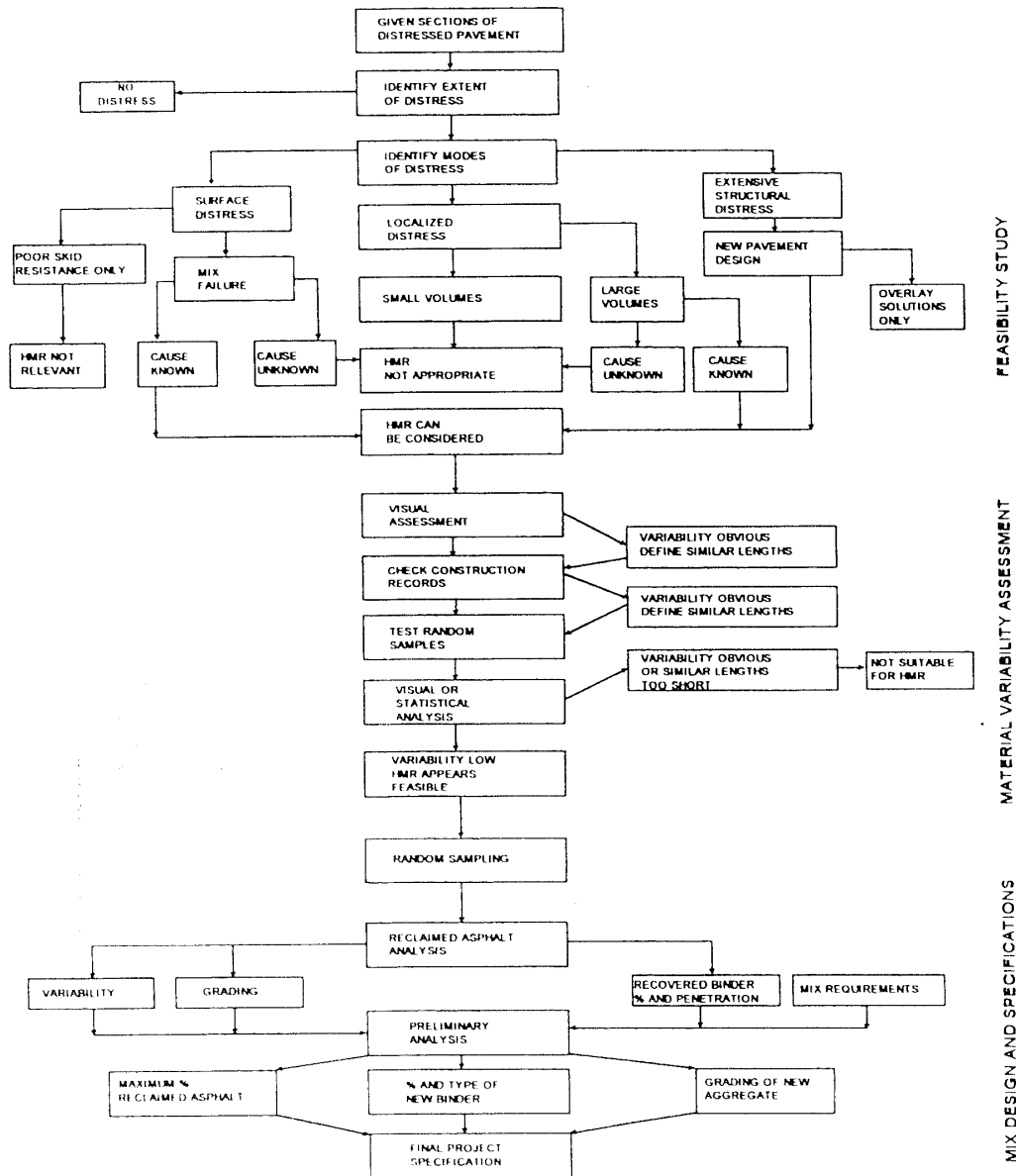
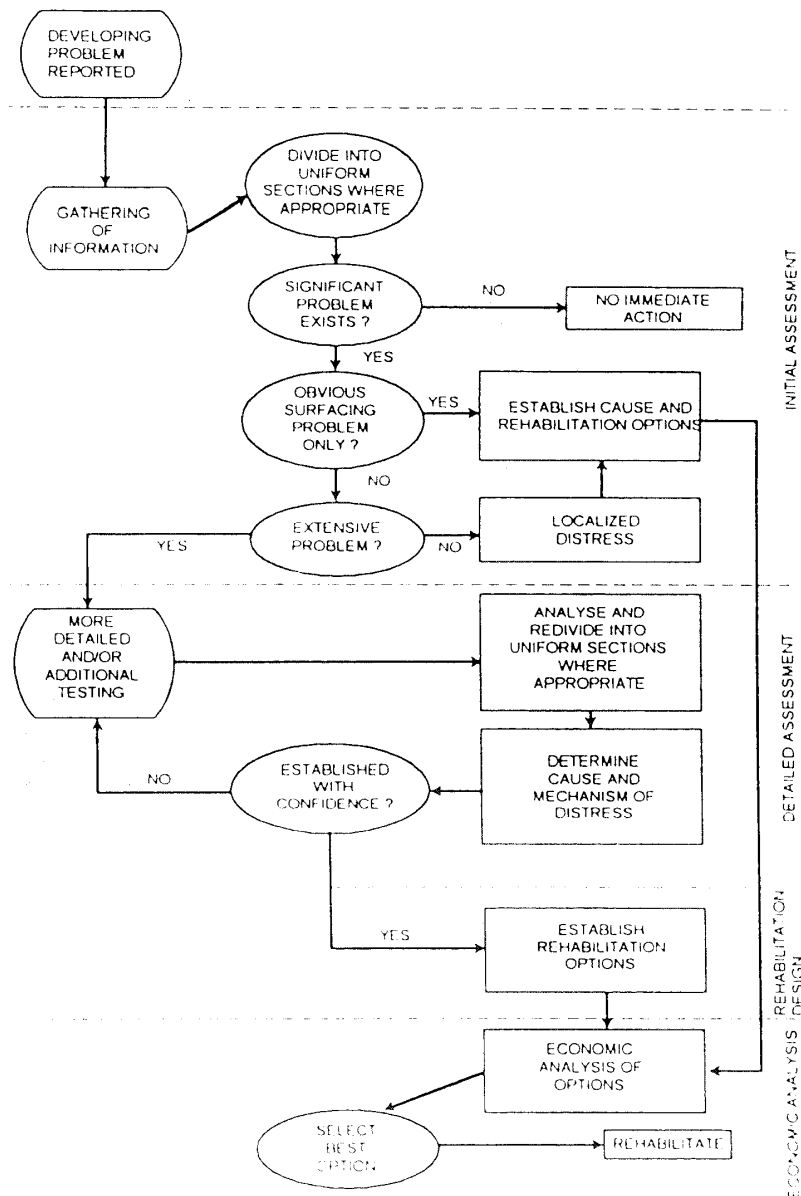


FIGURE 2: TECHNICAL FEASIBILITY INVESTIGATION



Source: Draft TRH12 (7)

FIGURE 3: FLOW DIAGRAM OF REHABILITATION DESIGN PROCEDURE

Surfacing distress only

Surfacing distress usually manifests itself in one or more of the following ways:

- *Poor skid resistance:* this is not normally remedied by hot mix recycling (hot surface recycling may be used – this would depend on the cause of distress).
- *Poor rideability:* it is essential that the mechanism of distress be accurately identified. Poor rideability can be caused either by creep deformation of the surfacing or failure of the underlying layers of the pavement. Failure of underlying layers means that this is a structural problem and must be treated accordingly.

Other reasons for distress are brittle surfacings, bleeding and stripping. Along with creep deformation of the asphalt, these phenomena should be considered as mix failures. Layers exhibiting any of these distress modes could be eminently suitable for hot mix recycling. However, in order to prevent any recurrence, it is essential that a comprehensive test program be implemented to determine the precise reason for the failure. If the results are inconclusive the mix should not be recycled except perhaps at very low ratios – less than one part reclaimed asphalt to six parts new material – as there exists a real danger of perpetuating the problem.

Localised factors causing distress

Again, the mechanism needs to be accurately identified. Localised distress is usually linked to poor surface or subsurface drainage, or to topographical or geological features. In general, localised distress is not remedied by hot mix recycling unless large quantities of material are involved, thereby making it an economic proposition.

Extensive structural distress

If the pavement is found to be structurally inadequate due either to limitations in the structural capacity or to poor material properties, it will be necessary to carry out a new design, using the procedures outlined in Draft TRH12 (7). The materials used in rehabilitating the pavement can be either new or recycled.

In order for sections of pavements to qualify for consideration for hot mix recycling the following criteria must be satisfied:

- The existing surface and/or base must consist of asphalt with a minimum of one lane width and a minimum thickness of 30 mm.
- Localised failures must be able to generate volumes of reclaimed asphalt large enough to make hot mix recycling economically viable. *(NB: In urban areas it is feasible and economic to recycle the reclaimed material by mixing it in very low proportions – less than 1:6 – with new materials. By using such proportions the problem of variability of the reclaimed asphalt becomes negligible.)*
- The use of reclaimed material in order to meet the required asphalt design must be feasible.

In addition, the following must be taken into consideration:

- Areas of similar thickness and type of asphalt must be identified, so that milling thicknesses can be specified. This does not, however, constitute a variable in terms of mix design.
- Mix failures must be investigated and the causes identified so that they may be minimised or eliminated in the recycled product.

4.2.2 Material variability assessment

Once potential sections for possible hot mix recycling have been identified, the material variability needs to be determined. The following approach is recommended:

- A visual assessment is made of the areas identified as distressed. It is important to look for any indications of change in the mix. This would include an examination of rolled-in chippings for change in stone type or size; changes in the overall colour of the surface are indicative of changes in aggregate or binder content.
- Existing records of construction are scrutinised in order to determine beginnings and ends of contracts and changes in mix design.
- Based on the above data, lengths of similar mix design are identified. Random samples may be taken in order to determine variability within these lengths. The variables in the reclaimed material which are routinely identified in hot mix recycling projects are:
 - asphalt type, layer thickness and density of the mix
 - aggregate type and grading
 - binder type and content
 - recovered binder penetration (and viscosity if required)
 - presence of surface treatments.

Recycled mixes should conform to specifications in terms of grading, binder content, and recovered binder penetration/viscosity. Variations in these properties in the reclaimed asphalt may affect the feasibility for recycling, or at least limit the proportion of reclaimed material in the mix.

It is suggested that already defined lengths be sampled, with a recommended average test frequency of at least one sample per 100 tons of potential reclaimed asphalt. (On a 50 mm thick layer this will give approximately one sample per 900m² or four samples per kilometre per lane.) A minimum of six samples per defined length should be assessed. The samples should be tested for binder content, grading, and recovered binder penetration/viscosity.

The results of these tests should be statistically analysed (the gradings in terms of percentages of coarse aggregate and filler) to determine the means and standard deviations. The variability of the reclaimed material may decrease due to mixing in the stockpile. However, it must be realised that if the standard deviations of these variables are higher than those required for compliance with a statistically based final recycled mix specification, the chances of obtaining an acceptable product when using high percentages of reclaimed material in the mix are remote.

In order to assess the variability of the mix of reclaimed and new materials the following relationships may be used:

$$\text{Var B} = [\alpha^2 \text{Var (R)} + \beta^2 \text{Var (N)}]$$

where Var = variance = square of the standard deviation
and Var B = variance of blend
 Var R = variance of reclaimed
 Var N = variance of new
and α and β are the mix proportions where $\alpha + \beta = 1$

The results of random testing can be scrutinized either visually or by a statistical analysis of variance in order to check that identified lengths are composed of an acceptably similar mix. Certain short lengths may be found to consist of material which is either too high in variability or too limited in quantity to be economically recycled. If this is the case, they should be used to form foundations for stockpiles or as general fill.

4.2.3 Preliminary mix design

It is essential that trial mix designs are carried out so that realistic proportions of reclaimed to new material can be used in the economic analysis which is discussed in section 4.3. In order to reproduce as far as possible the conditions which will prevail during the contract, samples for the trial mixes should be obtained by trial milling if this is at all possible. When the samples are obtained from cores, cognisance should be taken of changes in the aggregate shape and size after milling. It should be noted that milling and stockpiling can have a major effect on recovered binder penetration/viscosity. Small samples will therefore need to be sealed if they are to be kept for any length of time.

In hot mix recycling the specified requirements for a selected mix have to be met by a blend of reclaimed and new materials. Analysis of the reclaimed material will determine its grading and its binder content and penetration / viscosity. This will enable the calculation of the maximum ratio of reclaimed material that can be used in a blend with new material to meet a particular hot mix asphalt specification.

The approach outlined in this section complements Draft TRH12 (7) with regard to the special considerations needed prior to the implementation of the hot mix recycling option. It provides the necessary input for the undertaking of the economic feasibility investigation, which in turn will determine whether hot mix recycling would be a viable rehabilitation option.

4.3 ECONOMIC FEASIBILITY

This section is divided into four main parts. The first part identifies the main elements of an economic analysis. In the second part a cost savings model, developed to estimate the relative cost savings associated with a recycling operation, is presented. The focus is on those aspects where hot mix recycling differs from conventional operations and on the resultant cost implications for the road authority or contractor. The third part addresses mix quality, expected life and risk. Finally, a procedure based on decision theory and incorporating probability concepts is described. This will facilitate making the choice between alternative rehabilitation options (3).

The procedures presented in this section can be used by road authorities, consultants and contractors when deciding on network- and project-levels.

4.3.1 The elements of an economic analysis

The total economics of pavement rehabilitation involves both the costs to the road authority as well as to the road users (8). The costs to the road authority arise from expenditure on rehabilitation and subsequent maintenance operations. Therefore, the economic analysis of rehabilitation options has to include two aspects, namely:

- an assessment of the construction costs of the various options in the locality concerned; and
- an assessment of the cost-effectiveness of each option over the analysis period (ie the expected service-life of each option has to be taken into account).

The costs to the road users arise from inadequate pavement service levels (eg riding quality) and delay costs during rehabilitation operations (especially in the case of heavily trafficked roads).

The costs associated with conventional asphalt operations are well-known to the road industry. Therefore, the potential economic benefits of hot mix recycling can be determined in terms of the savings that can be expected from using recycled rather than conventional asphalt. (When hot mix recycling is considered as a rehabilitation option on a particular project, it is logical that the removal of the existing asphalt and replacing it with new conventional asphalt will also be an option).

The focus of the economic feasibility assessment is on those aspects where hot mix recycling operations differ from conventional operations, and the resultant cost implications for the road authority or client. Although road user costs should be taken into account in any economic analysis of pavement rehabilitation options, it will not be addressed. These costs should, for all practical purposes, be similar for both options under consideration, namely the removal of the existing asphalt and the replacing thereof with either a recycled mix or a new conventional mix.

4.3.2 Construction costs — a cost savings model

Various factors influence the use of the hot mix recycling process and its associated cost savings. These include the following:

- the cost of new materials and any possible shortages of aggregate and binders
- relative haulage distances (ie for recycling versus conventional operations)
- the capital investment required to undertake a recycling operation
- the commitment of the road industry to the recycling process and the degree of competition
- the anticipated future demand for the process

In order to obtain a clear picture of the economic advantages of using recycled rather than conventional asphalt, a cost savings model was developed (9)(10) which takes all the quantifiable factors contributing to the cost of a recycling operation into account.

Factors related to the quality of the recycled mix and the risk or uncertainty with regard to its expected life are not considered explicitly in the cost model. A procedure whereby these factors can be taken into account in an economic analysis is discussed in the next subsection.

The cost savings model takes into account cost differences between recycling and conventional methods with regard to the following:

- savings in new material requirements
- haulage savings
- extra costs for reclaiming
- savings in reducing moisture contents
- plant modification costs
- removed asphalt disposal fees or revenues
- value of stockpiled reclaimed asphalt

The relationship of these factors and their contribution to cost savings are described below. The various cost-savings equations and a description of the symbols used are given in Appendix A.

Savings in new material requirements (S_{vm})

Asphalt consists of aggregate stone, sand, filler, and binder. The savings arising from the reduced requirements for each of these, when the existing material is recycled, are calculated by the model. The quantities of these materials depend on the size of the project, the mix design, and the proportion of reclaimed asphalt in the recycled mix.

The proportion of reclaimed asphalt in the recycled mix has by far the greatest influence on the total cost savings. However, a high proportion of reclaimed material is not a prerequisite for economical recycling. In fact a modest ratio of old material will frequently be preferable when considering grading requirements, plant limitations, and the availability of reclaimed asphalt (generally a minimum existing asphalt thickness of 30mm is needed for hot mix recycling to be considered). Furthermore, in urban areas it is feasible and economic to recycle the reclaimed material by mixing it in very low proportions (less than 1:6) with new materials. Up to 10 per cent of the cost of conventional asphalt can be saved in this way (10). Another advantage is that by using such low proportions the problem of variability of the reclaimed asphalt becomes negligible.

Haulage savings (S_h)

Haulage distances are different for each new material and depend on the locality of the rehabilitation project. The unit costs of haulage (per ton per kilometre) also differ; eg the haulage cost of filler normally includes a railway carriage charge. Depending on the situation, the removed or reclaimed asphalt can be hauled to spoil, to a stockpile for future use, or to the central plant for crushing and/or reprocessing. (Note that removed asphalt refers to old asphalt to be disposed of, whereas reclaimed asphalt refers to old asphalt reclaimed for recycling purposes).

Savings on haulage will therefore arise from the reduced demand for new materials. It will also be affected

by the distances from the project to the disposal site, stockpile and recycling plant, and by the quantities of removed or reclaimed material hauled to each destination. All these factors are included in the cost-savings equation for haulage.

Extra costs for reclaiming (S_r)

The existing old asphalt can be ripped, broken and removed (ie disposed of) in conventional operations, or it can be reclaimed for recycling purposes. Reclaiming is done by ripping, breaking and then crushing at the plant site or by cold milling. In the latter case the bulk is reduced and thus the unit cost of haulage is lower than in the former. On the other hand, the cost of ripping, breaking and crushing is normally lower than the cost of milling. The equation for the extra costs involved in reclaiming operations takes these factors into account.

Savings in reducing moisture contents (S_m)

Moisture in the new aggregate (stone and sand) and where present in the reclaimed material, must be dried off in the recycling process. The moisture content of these materials varies and the unit cost of reducing it (per ton per percent) differs for each material.

Generally, new aggregate has a higher moisture content than reclaimed asphalt. Therefore costs are reduced in the drying process because less new aggregate is needed in recycling operations.

Plant modification costs (S_p)

Amortization costs associated with plant specialization and modification for hot mix recycling can be minimized if distributed over large quantities of hot mix, but can be substantial if only small amounts are produced. Therefore, the prospects for further work and the flexibility of the plant (ie whether it can be used for both recycling and conventional operations) will greatly influence the cost of the process or the cost savings on any project.

A complex plant, however, is not a prerequisite for economical recycling. A producer can choose to recycle material to specified standards (by using low proportions of reclaimed asphalt) without investing in complex plant modifications or new plant. Conversely, with modified or specially designed drum-mixers, higher proportions of reclaimed asphalt can be used with the potential for much greater cost savings.

In the cost savings model, the portion of the plant modification costs carried by a particular project is calculated by multiplying the total tonnage of recycled asphalt to be produced for that project with an average plant modification cost per ton of mix.

Removed material disposal fees or revenues (S_{rd})

The disposal of removed asphalt could entail spoil fees or revenues. The savings arising from not incurring spoil fees, or the loss of revenue from removed material disposed of, are calculated in the cost savings model.

Value of stockpiled reclaimed material (S_{rs})

Reclaimed material, stockpiled for future use, has an inherent value. In metropolitan areas the value of reclaimed asphalt can be considerable. Potential cost savings are therefore not necessarily limited to a particular project. If recycling is not deemed desirable for a certain project, the old asphalt can still be used on other projects.

In the cost savings model, the value of a stockpile of reclaimed asphalt in any location is calculated by multiplying the quantity of material in the stockpile with the value of a ton of reclaimed asphalt in that location.

Total cost savings (St)

The total cost savings that can be expected from using hot mix recycling rather than conventional operations are given by the sum of the above cost savings and extra cost equations as follows:

$$St = Svm + Sh - Sr + Sm - Sp + Srd + Srs$$

Use of the model

The cost savings model presented in this section is not meant for the accurate costing of individual jobs (11)(12)(13). It can, however, be used effectively for the following purposes:

- to estimate the savings that can be expected from using recycled rather than conventional asphalt
- to give road authorities an idea of the overall economic consequences of using hot mix recycling
- to investigate under what circumstances recycling is likely to be an economical rehabilitation option
- to assess the sensitivity and relative importance of the various contributing factors for particular recycling situations.

4.3.3 Quality, expected life and risk

The cost savings model given in the previous section merely provides a means of calculating the difference in construction costs between two possible rehabilitation options, one with and one without the use of hot mix recycling. The basic premise underlying the model is that the quality and life expectancy of a recycled mix is equivalent to that of a conventional asphalt mix. However, the possible difference in quality and, therefore, in expected service-life constitutes a risk that must be brought into the economic evaluation.

In general, the quality of an asphalt mix, whether conventional or recycled, is measured in terms of achieved end-product specifications and a balance between fatigue, permanent deformation and long-term durability characteristics. Although both recycled and conventional mixes have to satisfy the same quality requirements, there are, in the case of hot mix recycling, some factors which may make the achieving of these requirements more difficult. These factors are related to the following:

- inadequate control of the reclaiming and reprocessing operations
- the difficulty in controlling the composition and uniformity of the reclaimed asphalt
- uncertainty about the properties of a mix containing significant proportions of reclaimed binder
- uncertainty about the binder mixing efficiency during the recycling process

Research conducted in South Africa and elsewhere has indicated that, under carefully controlled conditions, the above factors have no significant influence on mix quality. More specifically, it was shown (14) that the proportion of reclaimed material in recycled mixes has no adverse effect *per se* on the quality of these mixes. It was also found (15)(16) that the quality of recycled mixes containing various proportions of reclaimed material compares well with conventional asphalt with regard to normal specification criteria, fatigue and permanent deformation resistance, and long-term durability.

However, in practice, such carefully controlled conditions are rarely found and there is little doubt that hot mix recycling involves more risk than conventional operations. This is mainly due to the higher complexity of the process, the possibility that adequate control is not exercised over the important variables (eg the uniformity of the reclaimed material) and the possible lack of recycling experience on the part of the contractor.

The inherent risk involved in hot mix recycling (or any rehabilitation operation), normally expressed as a probability of failure after a certain period of time, must be taken into consideration when an evaluation is made of possible rehabilitation options. This can be done by using probability concepts and decision theory.

4.3.4 Choosing a rehabilitation option using decision theory

In selecting a rehabilitation strategy for a particular project, cost information must be projected for the service-life of the project or for an appropriate analysis period. To conduct the analysis the following information is needed for each rehabilitation option:

- the initial construction cost
- the expected life
- the possible outcomes following the implementation of the option and the action to be taken in each event
- the cost of each outcome, ie the cost of subsequent rehabilitation work
- the probability of each outcome

Furthermore, decisions have to be made regarding an appropriate discount rate, a suitable analysis period and a salvage value for the pavement at the end of the analysis period.

On this basis the expected cost of each option can be calculated taking into account the time value of money and, for each option, the possible outcomes and their respective probabilities and costs. This approach allows the decision-maker to assess the risk involved in each option and to take this into account in the economic evaluation.

An example illustrating the above concepts for the choice between recycled and conventional mixes is given in Appendix B.

4.3.5 Economic analysis at network and project levels

The procedures for economic analysis presented in this document can be used at both network and project decision-making levels, the main difference being the amount of detailed information required.

Considering the needs of the entire road network, the purpose of economic analysis at a network level is to facilitate the efficient and optimal allocation of limited funds. With regard to hot mix recycling, the rehabilitation programme of a road authority could be analysed to identify projects which lend themselves to this process. Using average cost factors, the total expected savings for the duration of the programme could be calculated. Road authorities could then decide whether or not to encourage the use of hot mix recycling on their road networks.

At a project level, the emphasis is on the comparison of feasible rehabilitation alternatives and the selection of the most economical one. Accurate estimates of the relevant cost factors applicable to a particular project have to be used. Although the actual cost of a recycling operation will depend on contractors' tender prices, designers can use this documents' procedures to determine the relative influence of various factors on expected cost savings. Furthermore, expected cost savings can be related to the risk involved and the most economical option for the particular rehabilitation design period can be selected.

5 MIX DESIGN PROCEDURE

This section provides a mix design procedure that covers both the pre- and post-tender stages. The aim during the pre-tender stage is to provide contractors with information regarding feasible mix designs in order to facilitate the tendering process. During the post-tender stage, the focus is on the development of a final mix formulation that satisfies all relevant criteria and takes into account conditions pertaining to the project under consideration. The use of recycling additives in hot mix recycling, and the process of determining the correct type and amount of additive through chemical compositional analyses, are also discussed.

5.1 ENGINEERING PROPERTIES OF ASPHALT MIXES

In general, acceptable performance of an asphalt mix is achieved by a balance between three primary engineering properties, namely:

- durability;
- resistance to cracking (ie fatigue); and
- resistance to permanent deformation.

The above properties are affected by numerous factors. These include:

- aggregate grading, shape, type and packing
- binder content and type
- mix and compaction temperatures
- degree of compaction
- asphalt thickness
- percentage of air voids in the mix
- traffic loading and thermal and shrinkage forces
- bonding to the underlying layer and compaction during construction
- environmental conditions such as surface temperatures, sunlight and rainfall

These factors are catered for in the design of conventional asphalt mixes. See Draft TRH8 (17).

Although mixes used in hot mix recycling have nominally the same composition as conventional mixes, there are additional factors which need to be considered. These are related to the composition and uniformity of the reclaimed asphalt and the residual properties of the reclaimed binder. These additional factors necessitate a mix design procedure specifically aimed at hot mix recycling (2).

5.2 LABORATORY MIX DESIGN

The purpose of the laboratory mix design process is twofold, namely:

- to determine whether the existing asphalt can be recycled to produce a resultant mix with properties similar to that of a conventional mix, ie to eliminate misconceptions and uncertainty with regard to the applicability of hot mix recycling ; and
- to provide contractors with guidelines regarding feasible mix compositions for tendering purposes.

The mix design process can be divided into four phases, namely:

- 1 the characterisation of reclaimed and new materials
- 2 the determination of the proportions of reclaimed and new aggregate
- 3 the determination of the quantity and type of new binder to be added
- 4 mix preparation and testing.

5.2.1 Characterisation of reclaimed and new materials

Representative samples of the asphalt to be recycled must be obtained. The identification of sections of road with similar asphalt mix designs and the random sampling of each of these sections was discussed earlier.

In order to reproduce as far as possible the conditions that will prevail during the contract, asphalt samples should be obtained by milling. If this is not possible, asphalt slabs rather than cores should be used. Care must be taken not to include the cut edges of the slab in the sample. Furthermore, cognisance should be taken of changes that may occur in the aggregate grading as a result of milling operations. Previous experience with milling machines on a similar type of asphalt can provide guidelines. Alternatively, the gradation adjustment method developed by the Florida Department of Transportation (13) can be used (see Appendix C).

The uniformity of the material and the average layer thickness will have been determined during the technical feasibility study. In order to characterise the samples of existing asphalt the following must be established:

- the binder content of the asphalt
- the penetration, softening point and ductility of the recovered binder
- the grading and quality of the recovered aggregate

Standard test methods, most of which are described in TMH1 (18), must be used for the determination of the above properties. The binder in the reclaimed asphalt could be recovered using the Abson method (ASTM D.1856-65) with nitration grade benzene or reagent grade trichloroethylene.

The following values for the properties of the recovered old binder can be used to identify reclaimed asphalt which may not be suitable for hot mix recycling:

- recovered binder penetration less than 10
- binder softening point higher than 60°C
- binder ductility (at 25°C) less than 200 mm

The presence of one or more of the above limiting values will indicate the need for specialised chemical analyses in order to establish whether a recycling additive or a combination of additive and penetration/road grade binder will be able to restore the properties of the aged binder (19). This process is discussed fully in section 5.4.

With regard to new material, samples of the new aggregate types and sizes which will be available on the rehabilitation contract or, alternatively, similar types and sizes, should be obtained for grading determinations and for testing to establish conformity with the standard requirements for aggregate in asphalt (see Draft TRH8 (17)).

5.2.2 Determination of the proportions of reclaimed and new aggregate

The aim is to determine the optimum (ie the most economical) proportion of reclaimed asphalt in the final mix, and to ensure that the blend of reclaimed and new aggregate will result in a final grading which will perform satisfactorily in terms of stability and the distribution of traffic and environmental stresses.

A substantial quantity of new aggregate (20 % to 80 % depending on the reclaimed asphalt proportion) will be incorporated in the recycled mix. The proportions, types and sizes of new aggregate will depend on the following:

- the grading requirements of the type of layer to be constructed with regard to aggregate packing, stability, strength, and load transfer (see Draft TRH8 (17));
- the grading of the reclaimed aggregate;
- the types, sizes and gradings of available new aggregate;
- the quantity of reclaimed asphalt and thickness requirements of the final layer (ie whether or not the structural capacity of the pavement has to be improved);
- mixing plant limitations; eg if a drum mixer specifically designed for hot mix recycling is used, up to 70 % reclaimed material can be incorporated in the recycled mix, but if a modified batch plant is used, the proportion of reclaimed material has to be limited to between 30 and 40 %;
- skid resistance requirements (for surfacings);
- economic considerations, and
- the policies and/or requirements of a particular client.

The above factors will give a good indication of the demand for new aggregate. However, the process of determining the most suitable proportions and the combined grading of the new aggregate is largely iterative. A good starting point is to identify an appropriate grading specification, known to perform satisfactorily for the recycled mix, using Draft TRH8 (17). Various blends of reclaimed and new aggregate can then be made up and evaluated for their suitability. A procedure to blend different stone sizes to a given aggregate grading is described in Draft TRH8 (17).

As indicated above, the process of arriving at a final grading involves many trade-offs and due consideration should be given to the various influencing factors. The objective should not be to meet a particular grading specification at all costs, but rather to develop an optimum final grading in terms of individual project economics and expected performance.

5.2.3 Determination of the quantity and type of new binder

The quantity and type of new binder are determined by taking into account not only the need to supplement the reclaimed binder, but also the desired reconstitution of the properties of the aged binder to match those typically specified for conventional use.

The first step is to obtain an estimate of the final binder content in the recycled mix. This is done by blending the reclaimed aggregate (with the binder extracted) and new aggregate in the proportions determined above. The standard Marshall mix and testing procedure (see TMH1 (18)) is then applied for each combination of reclaimed and new material using a conventional penetration/road grade binder. During this step, the final binder content, type of binder, proportions of reclaimed and new aggregate, and the grading of the new aggregate can be adjusted in order to satisfy the desired mix design criteria (eg stability, flow, and air voids) for the type of mix under consideration (see Draft TRH8 (17)). Alternatively, the designer can use his/her experience with the binder demand of different types of asphalt to estimate the final binder content in the recycled mix.

The percentage of new binder required in the recycled mix can now be calculated using the estimated final binder content determined above, the proportion of reclaimed material and the binder content of the reclaimed asphalt (see Appendix D).

The final step is the selection of the type of new binder. With design values for penetration, the percentage of new binder in the recycled mix and the penetration of the binder in the reclaimed asphalt, the required penetration of the new binder can be determined using the nomograph given in Figure 4. If the required new binder is not a standard penetration/road grade binder, the following two options are available:

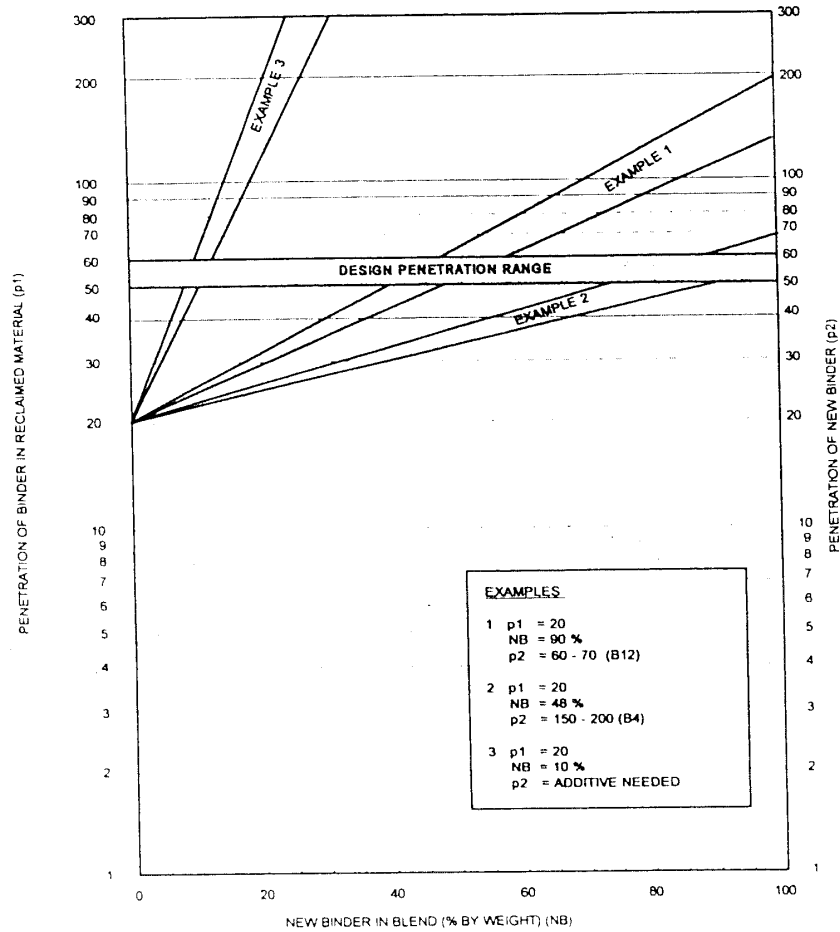
- The proportion of reclaimed asphalt in the resultant mix can be reduced, thereby effectively reducing the influence of the aged binder on the penetration of the final mix; or
- A recycling additive can be used, either on its own or in combination with a soft penetration/road grade binder.

The process of determining the correct type and amount of recycling additive and the accompanying chemical compositional analyses (19) are discussed in section 5.4. A summary of the mix design process and the relevant computational procedures is given in Appendix D.

5.2.4 Mix preparation and testing

The purpose of this phase is twofold, namely:

- to evaluate the effectiveness of the new binder in reconstituting the properties of the binder in the reclaimed asphalt; and
- to determine whether the engineering properties of the recycled mix are acceptable.



Source : Adapted from Servas (9)

FIGURE 4 USE OF NOMOGRAPH FOR DETERMINING THE REQUIRED GRADE AND PROPORTION OF NEW BINDER

The Marshall mix and testing procedure is repeated, using the previously determined proportions of reclaimed asphalt, new aggregate and new binder. New binders must be tested for conformity with the latest version of SABS307: Penetration grade bitumens.

Standard heating, mixing, curing and compaction procedures, as described in TMH1 (18), should be used for the preparation of Marshall specimens. Special consideration has however to be given to the treatment and incorporation of the reclaimed asphalt.

In the case of milled material, the reclaimed asphalt can be considered as just another new aggregate fraction and can therefore be treated in a similar way; ie preheat with the other new aggregate fractions to the specified temperature, thereafter thoroughly mix with the preheated new binder.

Alternatively, if it is deemed desirable at this stage to simulate actual plant conditions, at least to some extent, the new aggregate fractions can be "superheated" and then mixed with the reclaimed asphalt (at room temperature) and the preheated new binder. The determination of the temperature to which the new aggregate has to be heated in order to heat the reclaimed material, through heat transfer, to the desired temperature for compaction, involves complex thermodynamics. However, assuming a linear relationship, a rough estimate of this temperature can be calculated as follows:

$$T_n = \frac{T_c - (RA \cdot T_r + BN \cdot T_b)}{NA}$$

where

T_n	=	temperature of new aggregate before mixing
T_c	=	compaction temperature
T_r	=	temperature of reclaimed asphalt (unheated)
T_b	=	temperature of new binder before mixing
RA	=	amount of reclaimed asphalt in mix
NA	=	amount of new aggregate in mix
BN	=	amount of new binder in mix
with $RA + NA + BN$	=	1

When the existing asphalt is only available in the form of slabs, a different approach is necessary. Prior to mixing, the asphalt slabs have to be heated to between 50 and 70 degrees Celsius in order to facilitate the breaking up of the samples. Again, care must be taken not to include the cut edges of the slabs in the reclaimed asphalt sample. Following this preparation, the reclaimed material can be incorporated in the recycled mix in any of the two ways described above.

The optimum binder content for each reclaimed/new material combination is determined by varying the percentage of new binder. The specimens so produced must then be evaluated in order to determine the mix proportions that best satisfy all the mix design criteria for the type of mix under consideration. The normal requirements for conventional asphalt will prevail (see Draft TRH8 (17) and project specifications where applicable). However, the recovered penetration of the recycled binder after mixing needs to be specified. It is recommended that the following lower limits are adopted:

- Wearing course mix: 30 or 35 depending on type of mix and climatic region
- Base course mix: 30

- Subbase mix (under concrete): 25

Upper limits should be similar to values normally used for conventional material.

Once the final mix proportions have been obtained, additional asphalt briquettes should be fabricated to evaluate the engineering properties of the recycled mix. The following tests must be undertaken:

- the dynamic creep test, for permanent deformation characteristics ; and
- the static indirect tensile test, for tensile strength properties.

The dynamic creep modulus and tensile strength criteria are given in Draft TRH8 (17) . Refer also to the project specifications where applicable.

Although the above laboratory mix design procedure was described as a sequential process, it should be realised that in practice such a fixed sequence must not necessarily be followed. A trial and error method of determining suitable designs, based on prior experience and good engineering judgement, may also be acceptable as long as the final mix formulations satisfy the specification requirements. However, it is unlikely that the most economical design will be developed on a trial and error basis.

5.3 FINAL MIX DESIGN

The final mix design process can be divided into a laboratory and a field phase.

5.3.1 Laboratory phase

After the tender for the rehabilitation project has been awarded and a couple of weeks prior to the start of construction, the recycled mix design can be finalised.

The final mix design process follows essentially the same procedure as the laboratory mix design process. However, at this stage, the contractor has to provide the designer with asphalt samples that have been reclaimed in the same way that will be used during the project, and with aggregate and binder samples from the suppliers that he/she intends to use.

Using the designs developed during the laboratory mix design stage as a starting point, the designer can now proceed with the final design, taking into consideration not only the limitations of the contractor's mixing plant, but also his/her capabilities and expertise with regard to hot mix recycling.

Mix preparation must resemble actual plant conditions as far as possible, and the heat-transfer method, described in an earlier section, must be used. The various mix formulations must then be tested for compliance with the end product criteria given in Draft TRH8 (17), the final recovered binder penetration values recommended above, and with any other specifications which may apply to the particular contract.

5.3.2 Field phase

The purpose of this phase is to verify the final laboratory mix design under actual construction conditions and for the contractor to demonstrate his/her ability to produce the specified mix.

Using the final laboratory mix proportions, the contractor must produce the recycled mix and lay a trial section. Three mixes should be produced with the binder content varied 0,5% above and below the laboratory optimum. Samples must be taken at the plant for the preparation of asphalt briquettes. These briquettes must then be tested for all the specified properties. Special attention should be given to the binder content/air void relationship and the recovered binder penetration. Cores must also be obtained from the compacted trial section for visual inspection, the determination of the degree of compaction and standard testing. Other factors, such as coating and paveability, must also be assessed.

5.3.3 Quality control

During the construction phase, standard quality control procedures should be followed.

5.4 RECYCLING ADDITIVES

Asphalt modifiers, such as softening agents, rejuvenators, flux and aromatic oils, have been used as additives in the recycling of bituminous pavement materials in attempts to rejuvenate hard and brittle aged binders. In hot mix recycling, additives are particularly applicable where the ratio of reclaimed to new material is high. These additives are used either alone or in combination with new conventional bitumens.

Each different modifier has distinct chemical and fluxing effects on a particular aged binder. Similarly, a given modifier affects different aged binders in different ways. Other factors, such as mixing temperatures, mixing times and reclaimed/new material ratios, also have an effect. Naturally, when an additive is combined with a new binder the picture is further complicated.

There is little doubt that additives can play an increasing role in recycling. However, there is still some controversy regarding their use. Therefore, special care needs to be exercised in the selection and use of additives. A comprehensive method for the effective determination of the correct type and amount of additive when this is required in hot mix recycling operations, is discussed below.

5.4.1 The need for additives in hot mix recycling

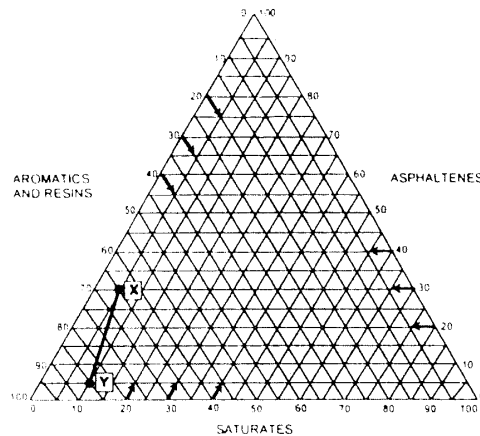
As discussed in section 5.2.3, the required penetration/road grade bitumen and/or the need for a recycling additive can be derived using a nomograph. Figure 4 illustrates that recycling additives are needed when commercially available penetration/road grade bitumens cannot rejuvenate the existing binder adequately. This happens when the ratio of reclaimed to new material is high and/or when the reclaimed material contains a particularly hard binder.

The correct type and amount of a recycling additive could be determined from fluxing power plots of available additives if penetration was the sole criterion of a rejuvenated binder's performance. However, binders are more complicated than that and their chemical composition also needs to be taken into account.

Chemical analysis is used to determine the composition of the reclaimed binder and thus to establish the composition of recycling additives needed to produce an acceptable final binder. This analysis is used in conjunction with the binder penetration and binder content of the reclaimed material, the reclaimed to new material ratio, and the required binder content in the recycled mix to determine the appropriate type and amount of recycling additive (19).

5.4.2 Determination of type and amount of recycling additive

New and reclaimed bitumens and available additives are analysed to determine their chemical composition. Their saturate, asphaltene, and aromatic and resin fractions can be determined using the traditional open column method (20) or preferably the high performance liquid chromatography (HPLC) approach (19). These values are plotted on a triangular graph (eg Figure 5) each side of which gives the percentage content of one of the above three fractions. Therefore any point on this graph represents the interception of three percentage value lines and thus the chemical composition of a particular bitumen or recycling additive.



Source: Servas (9)

FIGURE 5: BITUMINOUS BINDER COMPOSITION CHART

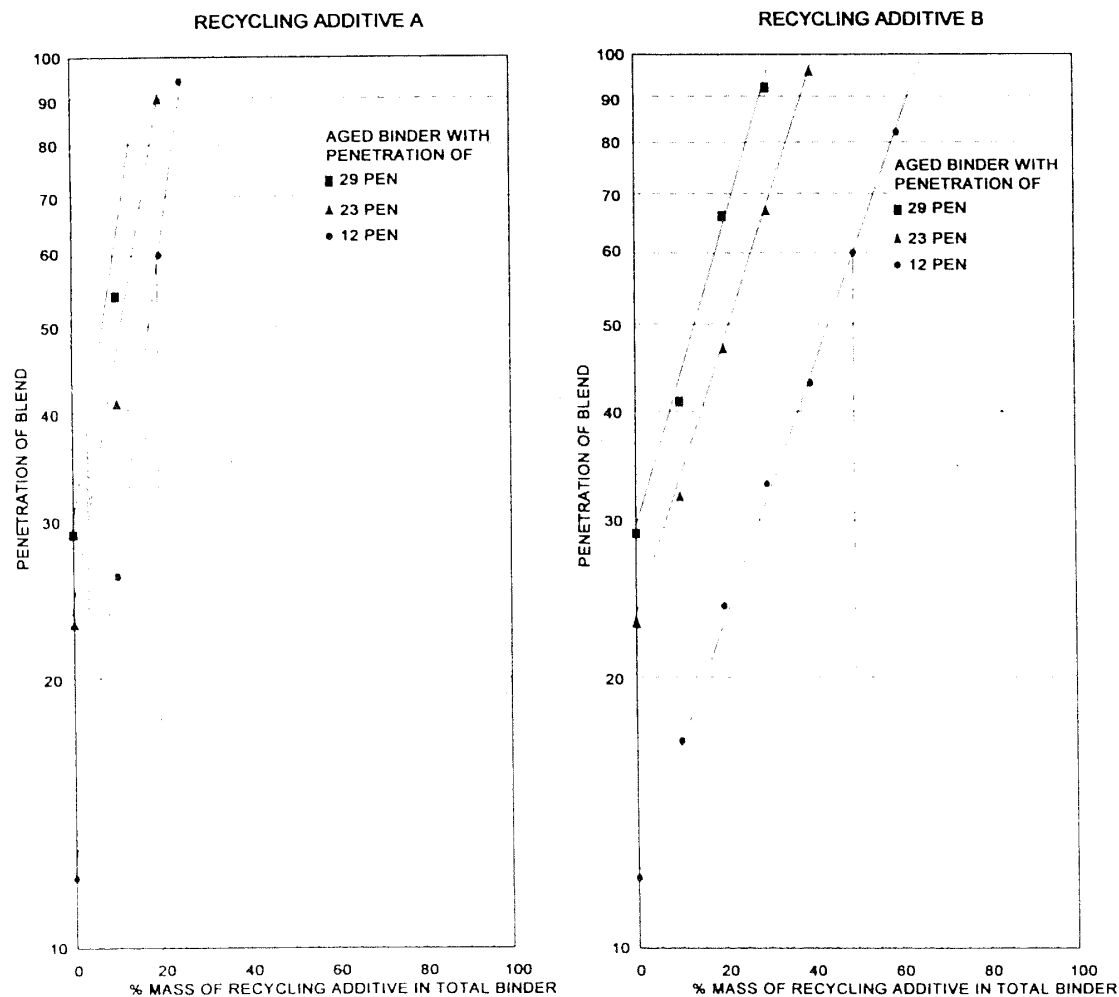
Satisfactory bitumens will fall in a particular area within the graph and bitumens that have performed adequately should be analysed in order to define its parameters. Aged bitumens are likely to fall well outside this area and it is the function of recycling additives (when the use of penetration/road grade binders will not suffice) to bring them back within the required parameters.

In the example shown in Figure 5, X represents an aged binder having 30 per cent asphaltenes, 65 per cent aromatics and resin and 5 per cent saturates and Y a recycling additive with 5 per cent asphaltenes, 85 per cent aromatics and resins and 10 per cent saturates. Their blending will result in a binder with composition along the XY line, assuming a linear relationship

In parallel with the above analysis, the relative effect of available additives on the penetration of the reclaimed binder needs to be assessed. This is done by combining these additives in various proportions with the reclaimed (aged) binder and measuring the penetration of the blends. For each recycling additive, graphs (such as those shown in Figure 6) are drawn of the percentage additive in the total binder versus the log of the penetration of the blend. These graphs are used to choose the most suitable additive for particular reclaimed materials and reclaimed to new material ratios

The examples given in Figure 6 show that additive A has a greater fluxing power than additive B. An aged binder with penetration of 12 needs to be combined with 20 per cent of additive A or 50 per cent of additive B to produce a blend with penetration of 60. The selection of additive A or B depends on the required percentage of a new binder in the final blend.

For simplicity, the above examples illustrate the procedure followed in cases where a recycling additive is used alone to rejuvenate an aged binder. However, in general, recycling additives are used in conjunction with new penetration grade bitumens. The approach remains basically the same, albeit more involved. The chemical analysis in these cases includes the new bitumen whose chemical composition is also taken into account. Similarly its fluxing power is considered together with that of suitable recycling additives in determining the most appropriate combination for particular blends and reclaimed binders.



Source: Adapted from Servas (9)

FIGURE 6: THE FLUXING POWERS OF TWO RECYCLING ADDITIVES

6 RECLAIMING AND STOCKPILING TECHNIQUES

Research has shown (15)(16) that the quality of recycled mixes containing various proportions of reclaimed asphalt compares well with conventional asphalt as regards normal specifications, fatigue and permanent deformation resistance, and durability. However, underlying these findings is the assumption that in practice correct procedures are adopted and adequate control is exercised over the recycling operations.

The quality and integrity of the reclaimed material is the most important factor determining the quality of a recycled mix and hence the success of the recycling operation. This quality depends largely on the asphalt reclamation and stockpiling processes. Proper control over reclaiming operations and the stockpiling of reclaimed asphalt can therefore contribute markedly towards ensuring a high-quality end-product (4).

6.1 ASPHALT RECLAIMING

Asphalt reclaiming involves techniques used to recover existing asphalt pavement material from a road and the processing of this material to make it suitable for reuse (21).

6.1.1 Reclaiming techniques

Two broad methods of reclaiming bituminous pavement material for subsequent reuse can be identified:

- The traditional full-depth pavement removal method incorporating ripping, breaking and crushing.
- Cold milling which involves the automatically controlled removal of pavement material to a desired depth with specially designed equipment.

6.1.2 Ripping and crushing

This technique of asphalt reclaiming involves the loosening and breaking-up of an in situ asphalt layer by tines or some type of impact technique, and the subsequent crushing of the material at a central plant to a prescribed grading envelope.

When reclaiming bituminous pavement material by ripping, three or more passes may be required to rip-out a full lane width (depending, of course, on factors such as layer thickness, and geometric constraints). Although a layer of any thickness can be ripped successfully, a minimum of 30 mm is normally required for hot mix recycling purposes. Different types of conventional construction equipment can be used to rip the existing asphalt layer, including one-shank ripper attachments on motor graders, crawler tractors or bulldozers, or purpose-designed scarifying units attached to conventional equipment. After ripping, equipment such as grid rollers break the material down to a size suitable for primary crushing. The broken material is then transported to a central plant or storage site for crushing or storage.

Crushing is normally undertaken at a central plant site. Primary and secondary crushing operations reduce the material to the grading specification (normally 37,5 mm maximum size) for reclaimed asphalt used to produce recycled asphalt. The crushing of reclaimed asphalt does not present special problems: it can be undertaken in hot weather and does not require heavy-duty units. Conventional portable crushing and screening equipment can be used or, alternatively, equipment designed specifically for the crushing of reclaimed asphalt (22)

The secret of successful crushing operations seems to lie in not 'crowding' the crushing equipment, particularly on warm days (ambient temperature above 22 degrees Celsius). Furthermore, in selecting the crushing equipment, the possible increase of fines must be considered. This must be minimized to avoid lowering the percentage of reclaimed material in the recycled mix (because of the degradation of the material) to a level below that which would have been appropriate.

6.1.3 Cold milling

Cold milling is a controlled pavement removal process that performs tailored, full or partial depth removal and profiling of an asphalt pavement, by a machine equipped with a rotary cutting drum.

Milling machines are available in various sizes from several manufacturers. They are generally equipped with an automatic grade and slope control system, an adaptable conveyor system for offset or in-line truck loading, variable depth of cut which can be controlled to relatively close tolerances (an accuracy of 2 to 3 mm can be expected on most machines), and water-spray units designed to control the development of dust during the milling operation and to reduce cutting-tool wear (by keeping them cool). Some of the more sophisticated machines also incorporate a variable cutting width facility. Furthermore, the maximum size and grading of milled material produced can be controlled, in line with design requirements, by changing the type of cutting tools and/or their configuration, the forward speed of the machine and the depth of cut. For recycling operations the maximum size of milled material should not exceed 37,5 mm.

Most milling machines cut upwards, that is from the bottom to the top, as the machine moves forward. The maximum depth of material which can be removed in one pass is about 40 mm by a small machine and up to 150 mm by a large machine, depending on working conditions (including ambient temperature) and the composition of the asphalt mix. The practical layer thickness that can be milled in one pass generally varies between 50 and 75 mm. Normally a minimum thickness of 30 mm is required if the material is to be used for hot mix recycling. Since the depth of cut can also be controlled manually, variations in the thickness of the existing layer can be accommodated, depending, of course, on the expertise and skill of the operator. After milling the pavement surface has to be broomed before repaving in order to remove loose material (spillage).

The productivity of milling machines varies considerably and depends on, amongst other things, the following:

- the resistance of the material to the penetration of the cutting tools: this is a function of the type of mix and the viscosity of the existing binder (13) ;
- pavement temperature ;
- the depth of cutting or milling ;
- the location of the project (rural or urban) ; and
- the systematic replacement of cutting tools to ensure that those in use retain their sharp cutting edge.

6.2 FACTORS INFLUENCING THE CHOICE OF A RECLAIMING TECHNIQUE

The choice of a reclaiming technique depends on project-specific considerations. The following factors

have to be taken into account:

- the type of rehabilitation project; ie whether the rehabilitation design calls for the total or partial reconstruction of the underlying layers or the treatment of the surfacing only
- whether the road can be closed to traffic or whether rehabilitation work has to be done while part of the road is still open
- whether the whole or only part of the carriageway width is involved and whether rehabilitation includes the full length or only sections along the length of the carriageway
- the purpose for which the reclaimed asphalt is to be used; ie on the particular project or not
- the proportions in which the reclaimed material is to be used; ie in high or low proportions in the recycled mix
- the quantity of existing material and layer thicknesses
- the uniformity and condition of the existing material
- the availability of equipment
- time and quality considerations
- economic considerations; ie the relative cost of alternative reclaiming techniques

A checklist which can be used as a guide for selecting the appropriate reclaiming method is given in Appendix E.

6.3 STOCKPILING

6.3.1 The need for stockpiling

Careful attention to the stockpiling of reclaimed asphalt cannot be overemphasized as the method of stockpiling and preserving the integrity of the material will have a direct influence on whether a high quality and uniform recycled mix can eventually be produced.

Reclaimed asphalt is generally stockpiled for the following reasons:

- to have the material at hand (at the plant site) for reuse in a recycled mix on the particular project from where it was reclaimed
- to store the material at a central plant or storage site for future use
- to reduce variability through the thorough mixing of the material in the stockpile

The form (ripped, crushed or milled) in which the material is stockpiled should depend on timing and intended use. A three-month or longer time lapse would make ripping the appropriate reclaiming technique and the material should be stockpiled in ripped form. If, on the other hand, the material is used shortly after removal, it can be stockpiled in crushed or milled form depending on the reclaiming technique used.

The intended use will determine the extent to which different types of reclaimed asphalt have to be stockpiled separately and the degree of quality control required. Important factors to be considered are:

- the type of project;
- the type of layer to be constructed;
- the composition and uniformity of the existing asphalt; and
- design requirements.

If a base course layer or surfacing is to contain a high proportion of the reclaimed material, it is imperative that it is stockpiled so that the material properties in a particular stockpile are consistent. However, if the reclaimed asphalt is to be used only in low proportions or for a lower layer (eg a subbase), separate stockpiles may not be necessary. In this case the variability can be reduced by the thorough mixing of the stockpiled materials prior to reuse in the recycling process.

Preserving the integrity of the reclaimed material is of paramount importance and so adequate provision must be made to prevent

- congealment or consolidation;
- contamination;
- size segregation; and
- moisture absorption and retention.

6.3.2 Construction of stockpiles and preservation measures

In the construction of a stockpile of reclaimed asphalt (milled or crushed), attention has to be given to the following:

- the site
- the size of the stockpile
- the prevention of consolidation, segregation, contamination, and moisture retention.

The site must be clean and all organic matter (eg grass) and other deleterious materials must be removed to prevent contamination. The site should not be located near a crusher or a concrete batching plant as the material can be contaminated with dust and cement. Furthermore, the area has to be graded to a free-draining profile and compacted to form a firm base. Preferably a cement-stabilized layer or a layer of well-compacted milled asphalt should be placed as a base for the stockpiles.

The size of the stockpile should depend on the intended storage period. If the material is to be stored for a relatively long period of time, a big stockpile is better as this will reduce the oxidation and hardening of the reclaimed binder. However, if the material is to be used shortly after removal, many small stockpiles (the size of a truck load) adjacent to one another are preferable as this will prevent the consolidation of the material.

The storage period, prevailing temperature conditions, the height of the stockpile, and the equipment used to construct it influence the consolidation of stockpiled materials. If preventive measures are not taken, the consolidated material will be unsuitable for recycling purposes unless it is resized or crushed at extra cost.

Milled material can be stockpiled by a front-end loader or the haulage trucks can dump the material in separate adjacent stockpiles. Bulldozers can dump and push material but should never be allowed to ride over the stockpile, as heavy equipment will consolidate and recompact the material and thus defeat the purpose of the milling process (23). Crushed material can be stockpiled using a moving radial stacking conveyor. Stationary stacking conveyors should be avoided as they cause severe segregation and excessive consolidation (because of the height of the stockpile) (21).

Consolidation can also be avoided by keeping the stockpile as low as possible. It should not exceed three metres thus preventing the recompacting of the material at the base. Horizontal stockpiles are therefore preferable to vertical ones.

To prevent segregation, large conical-shaped stockpiles should be avoided. As milled material is loaded on top of a conical stockpile, larger particles tend to roll to the outer rim. This problem is intensified as the stockpile grows larger (24). Stockpiles should therefore be flat and material removed across the stockpile face and not by point loading. If segregation does occur, the stockpile should be reworked before the material is used.

Reclaimed asphalt normally has a very low moisture content (generally below one percent (21)). However, rain on a stockpile can increase moisture content dramatically. High or variable moisture contents of reclaimed material will hamper mix production seriously. More energy will be needed to evaporate the excess moisture with the result that the proportion of reclaimed material in the recycled mix and/or the production rate may be reduced. Furthermore, the engineering properties of the recycled mix may be adversely affected. Proper drainage of the stockpile is therefore extremely important and covering the stockpile with waterproof material (eg tarpaulin) should be considered, especially if the storage period is relatively long.

Ideally, stockpiling should be kept to a minimum. This can be achieved by good scheduling and by treating the milling or crushing, asphalt production, and paving operations as a continuous process. In practice a stockpile that provides mixing plant requirements for about two days is needed to allow the reclaimed material to be tested, the stockpile to be properly mixed to reduce variability, and to give a safety margin for delays or breakdowns.

The stockpiling of ripped and broken asphalt (preferable for long-term storage) does not present any significant problems of consolidation, moisture retention and segregation. However, contamination of the material by organic or foreign matter must be prevented.

6.3.3 Quality control of stockpiles

The materials going into a particular stockpile should be carefully controlled and recorded to ensure a quality end-product. This is especially important if high proportions of reclaimed material are to be used in the recycling process. Then different types of reclaimed asphalt must be stockpiled separately, not only in terms of mix types, but also of binder quality and condition; eg dry, brittle mixes, relatively fresh mixes and mixes with extreme binder variation because of stripping.

The origin of the stockpile, grading, binder content, recovered binder penetration/viscosity, and where and when the material will be reused should be recorded.

6.3.4 Sampling of stockpiles

To sample a stockpile of reclaimed asphalt the same procedures should be used as would be required for other stockpiles; ie random selection to ensure that representative test samples are obtained (25)(26). For relatively uniform material, minimum frequencies of one sample per 200 tons for binder content and grading and one sample per 500 tons for recovered binder penetration/viscosity are suggested. These sampling frequencies should however be increased when more variable reclaimed material is encountered.

Materials with widely varying recovered binder penetration/viscosity values must be carefully identified. Variances, within and between stockpiles, greater than 20 percent of the average penetration/viscosity value should be investigated. Such materials should be remixed in the stockpile and retested and, if still found to be highly variable, treated separately for mix design purposes.

7 MIXING PLANT REQUIREMENTS

Hot mix recycling has been undertaken successfully using modified mixing plant of either the batch or drum-mixer types. These modifications range from simple additions to existing plant to highly complex equipment, preferably incorporated during the manufacture of new plant (5).

Modifications can enable conventional batch plants to be used successfully for recycling operations with substantial proportions of reclaimed material, depending on the type of plant and moisture content conditions. For most plants, the practical limit is considered to be between 30 and 40 per cent reclaimed material, although some plants are capable of processing higher proportions.

Through the use of modified or specially designed drum mixers, higher proportions of reclaimed asphalt in the recycled mix are possible. The acceptable limit for most types of equipment is about 70 per cent, although with some processes 100 per cent recycling is at least theoretically achievable.

7.1 BATCH PLANT RECYCLING

Hot mix recycling can be done in a batch-type asphalt plant by what can best be described as the "mixer heat transfer method". This method was first developed in Maplewood, Minnesota, and is also known as the "Minnesota method" (27). The process principle is based upon mixing overheated or superheated new aggregate with ambient temperature reclaimed material.

The reclaimed asphalt is introduced from a separate cold feed bin directly into the batch plant weigh hopper, by-passing the dryer, hot elevator and screen. The new aggregate is superheated in the conventional dryer and is introduced into the weigh hopper in the normal manner. The surplus heat in the new aggregate is transferred by conduction to the reclaimed asphalt while the materials are proportioned in the weigh hopper and then blended and mixed with additional new binder in the pugmill.

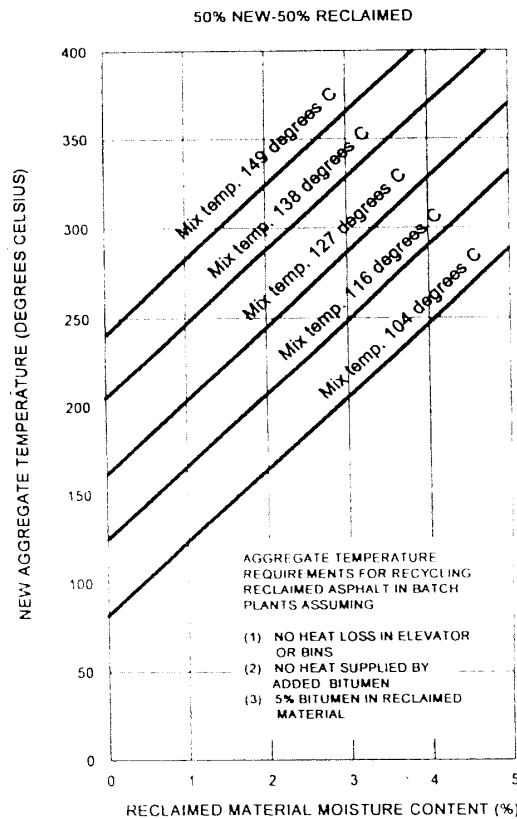
This process prevents both smoke pollution and material build-up problems in the dryer, hot elevator and screens, but is limited in the percentage of reclaimed material which can be used. This limitation is determined by the following:

- The temperature of the superheated aggregate: as the proportion of reclaimed asphalt in the recycled mix increases, the temperature to which new aggregate must be heated increases dramatically.
- The temperature of the stockpiled reclaimed material: a satisfactory and pollution-free method of preheating this material without damage to the existing binder has yet to be developed.
- The moisture content of the reclaimed material: as this becomes greater the required superheating of the new aggregate increases significantly. A high moisture content will also result in water vapour/steam emissions in the pugmill area.
- The specified discharge temperature of the recycled mix.
- The desired production rate.

Figure 7 illustrates the desired new aggregate temperature for a recycled mix with 50 per cent reclaimed asphalt and for various moisture contents of reclaimed material and final mix discharge temperatures.

The additional equipment required for recycling, using the "mixer heat transfer method", includes a cold feed bin and feeder specially designed to handle the more cohesive reclaimed material, a grizzly screen on top of the cold feed bin to remove oversize reclaimed material, a bucket elevator or conveyor to elevate the material to the weigh hopper, and the necessary electrical controls to integrate the new components (28)(29). The nature and cost of modifications would depend on, inter alia, the existing plant design, pollution control and material conveying equipment, as well as the magnitude of the intended recycling operation (i.e. output requirements).

An alternative method to the above is to introduce the reclaimed asphalt during the process of flow by adding it to the superheated aggregate at the discharge of the dryer. This approach, although considerably cheaper with regard to the modifications it necessitates, is generally not recommended as it has certain important shortcomings (9). These are associated with congealment and emissions during the elevating, screening (at times by-passed) and weighing processes, and result in the process being suitable only for producing mixes containing smaller proportions of reclaimed asphalt.



Source: Adapted from Grant (28)

FIGURE 7: REQUIRED NEW AGGREGATE TEMPERATURE FOR A RECYCLED MIX WITH 50% RECLAIMED MATERIAL

7.2 DRUM MIXER RECYCLING

Unmodified drum mixer plant has been used in various experimental recycling projects, mainly in the USA (22). The main problems encountered include smoke emission, material build-up inside the drum and damage to the old binder.

Despite the above problems, the recycled mixes obtained were sufficiently good to encourage further experimentation and development. Some of the more important modifications and developed systems included:

- low-temperature convection heating method;
- pyrocone system;
- twin drum system; and
- drum-within-a-drum system.

The centre-feed system is today the preferred drum mixer recycling method and has been adopted by most of the major plant manufacturers (23). With this method, the new aggregate is fed in at the burner end, and the reclaimed material is introduced at about the midpoint of the drum by means of a raffle wheel, where it is heated by the combined effect of the overheated new aggregate and the hot combustion gases. New binder is injected after the reclaimed asphalt and new aggregate have begun mixing. The reclaimed material is protected from direct contact with the burner flame by the dense veil of new aggregate, produced by specially designed flight arrangements.

Some of the main requirements with regard to the use of drum mixer plants for hot mix recycling are discussed below.

Reclaimed material cold feed

The cold feed bin used for reclaimed asphalt should have a relatively small capacity with steep sides and a large discharge opening. Attention should be given to the opening configuration. A feeder bin with a rectangular opening can contribute to segregation and the bridging of the material. It is therefore recommended that a self-relieving configuration be used, which should result in a more uniform flow of material (30). The belt feeder should be of the variable speed type to prevent packing and consolidation under high ambient temperatures.

A reasonably constant level of material should be maintained above the feeder gate of the cold feed bin, because if the bin is allowed to run too low, a reverse cone or drawdown in the centre may result (24). During operations, the cold feed should be monitored to prevent gaps in the material flow. Furthermore, at the end of the day's production, the reclaimed asphalt bin should be run empty as the material is likely to consolidate in the bin overnight.

Conveyor system

The conveyor system must be equipped with continuous weighing devices, suitably calibrated to enable accurate proportioning of the various materials, and the incline of the conveyors should be such that segregation does not occur. Also, to maintain the required proportion of new aggregate, reclaimed asphalt

and new bitumen, the conveyor system must be interlocked with the bitumen pump.

During operations, it is important to monitor the moisture content of reclaimed and new materials so that the wet weight measured by the belt scales can be corrected to the dry weight of the aggregate.

Binder feed

The binder feed control may be coupled with the aggregate weighing system by means of an integrator, so as to vary the feed rate automatically, as required to maintain the specified proportions. Alternatively, a percentage indicator may be fitted in the control room to control the pump and to maintain a constant ratio of binder to aggregate. With regard to the binder injection pump, greater accuracy is achieved when it is fitted with a header-tank which provides a constant head to the pump. Furthermore, it is desirable to use a variable speed motor with the injection pump. The binder storage tank temperature should be selected to achieve the required temperature pertaining to the type of binder used.

Inside the mixing unit, the spray nozzles should be adjusted to provide a uniform distribution of binder into the new and reclaimed materials. Ideally, the new binder should be added just prior to the evaporation of the moisture contained in the new and reclaimed materials, as the foaming action will facilitate coating and prevent separation of dust from the aggregate (28).

Heating and mixing unit

The length of the mixing unit must be such that adequate heating and mixing can be achieved. For hot mix recycling, it may be necessary and, indeed, more effective to extend the conventional drum length in order to provide longer time for the uniform heating of new aggregate, minimize damage to the reclaimed asphalt and ensure adequate mixing and coating.

The adequacy of mixing can be controlled by increasing or decreasing the retention time of materials inside the drum. This can be done by adjusting the slope of the drum, the drum rotation speed, or by using special flight arrangements. The flights inside the drum should be designed to ensure a dense and even veil of material in both the heating and mixing zones of the drum. This is especially important in order to provide the necessary protection for the binder in the reclaimed material from the burner flame.

Means must also be provided to control mix discharge temperatures by adjusting the rate of fuel and air being fed to the burner and mixing unit. In addition, the exhaust fan should be fitted with a suitable damper to control the draft through the drum.

The discharge chute from the drum should have a relatively small and narrow opening to prevent segregation and to force the mix into the centre of the drag conveyor or elevator used to transport the mix to the surge silo (30).

With regard to plant throughput capacity, it is important to realise that modified drum mixers normally have to be operated below their conventional capacity when recycling. The throughput rate must also be decreased when the moisture content of the reclaimed and new materials is on the high side or is variable.

Storage or surge silo

Transportation of the mix from the drum discharge to the storage silo can be by a skip- or slat-type

conveyor. A steep conveyor should not be used as it is likely to cause segregation of the mix.

The silo should be of the cylindrical type and insulated. The outlet cone should be heated, either electrically or by means of thermal oil, in order to facilitate mix discharge.

The techniques used to load and withdraw material from the surge silo may have an important influence on the preservation of the integrity of the mix, particularly as far as segregation is concerned. Proper procedures and techniques are discussed in detail in references (24) and (30).

Air pollution control

The extent of air pollution or stack emission from drum mixer recycling plant is a function of, *inter alia*, the following:

- the efficiency of dust collection and extraction equipment
- production or throughput rates
- burner efficiency
- mixing drum temperatures and drum gas velocity
- the method of heat transfer used
- the sequence of introducing new and reclaimed material
- the proportion of reclaimed asphalt in the recycled mix
- the "purity" of the reclaimed material with regard to, for example, the presence of tar
- reclaimed and new material moisture contents and moisture content variations.

The above has to be taken into consideration when deciding on the type of equipment (for example, wet scrubbers, dry collectors, fabric filters) and whether both primary and secondary collectors and extractors are needed.

8 CONTRACTUAL PROCEDURES AND SPECIFICATION GUIDELINES

A rehabilitation project incorporating the recycling of existing bituminous pavement material needs clear, unambiguous specifications to ensure a quality end-product. This section provides guidelines on contractual procedures and specifications unique to the hot mix recycling process (6) to be used in conjunction with current conventional asphalt standard specifications (31).

8.1 THE TENDER DOCUMENT – GENERAL ASPECTS

The following important aspects have to be given due consideration when developing a tender document for a hot mix recycling project:

- materials information to be provided to contractors to aid tendering activities
- the specification or not of hot mix recycling as the rehabilitation option
- the ownership of reclaimed asphalt
- the prescription or not of particular ratios of reclaimed to new material
- provision for variations from the nominal mix composition

These aspects are addressed in the following sub-sections.

8.1.1 Materials information

The information obtained in the technical feasibility and preliminary design stages should form the basis for the development of bid estimates by contractors, and should be made available without prejudice to the client. This information should include the following:

- the composition of the existing asphalt
- layer thicknesses
- the variability of the existing asphalt in terms of layer thicknesses, grading, binder content and recovered binder penetration/viscosity
- preliminary mix designs for percentages of reclaimed asphalt ranging from zero (or from the minimum percentage if specified) to the maximum feasible, at 20% increments (this would normally involve four mix designs per uniform length)
- estimated new aggregate and new binder requirements for different preliminary mix designs
- the mix composition to be used as the nominal mix for tendering purposes (this should be the most suitable of the preliminary mixes)
- estimated quantities of reclaimed asphalt available for recycling with allowance for normal wastage and poor quality materials
- samples of milled asphalt (if possible) so that tenderers may carry out their own designs.

This information, if provided, will not only assist contractors in the preparation of tenders, but will also provide a fair basis for tendering.

8.1.2 Methods of specifying hot mix recycling for rehabilitation

Deteriorated asphalt pavements may provide a source of high-quality materials which can be re-used effectively through hot mix recycling. Since these pavements belong to the road authorities, these authorities should, in national interest, encourage and actively support the initiative for re-using existing pavement material resources for road reconstruction and rehabilitation. Furthermore, they should create conditions and establish procedures that facilitate effective and economical recycling. For a rehabilitation project, where hot mix recycling seems feasible, this can be done in three ways:

- by specifying a conventional approach but allowing recycling; or
- by specifying recycling but allowing conventional alternatives; or
- by specifying recycling without the option of alternatives.

Deciding on which approach to follow is complex and will depend on, *inter alia*, the following:

- the influence that a particular approach may have on tender prices
- the extent to which hot mix recycling has been adopted by contractors
- the number of possible future recycling projects, which will have a marked influence on amortization costs associated with recycling plant and equipment
- the availability of alternative uses for reclaimed asphalt
- the location and complexity of the project
- the availability of suitable coarse and/or fine new aggregate.

Specifying a conventional approach but allowing recycling

Supporters of this approach (10)(32) argue that the removal and safeguarded availability of pavement material for recycling should be the main aim in rehabilitation projects. This can be achieved by incorporating in tender documents a statement such as:

"Bituminous mixes containing reclaimed asphalt will be accepted on an equal basis as conventional mixes, provided all the normal specification requirements are met."

The perceived advantages of such an approach are the following:

- the reclaimed asphalt may be used in any project, including, of course, the project from which the material was obtained (provided that the recycled product meets the appropriate specifications)
- the decision to recycle or not can be left with the contractor who should be able to use the reclaimed asphalt to the benefit of both himself and his client
- contractors will be able to tender for projects regardless of their ability to recycle or not
- contractors who have the technical knowledge will be able to offer a recycling alternative based on a reclaimed-to-new-material ratio with the confidence that they will be able to adhere to the specification requirements

- road authorities can be flexible regarding either the introduction of some measures to encourage the industry to recycle, or the specification of special tests for recycled mixes and restrictions on the proportion of reclaimed material in different pavement layers (which will provide additional safeguards).

The main disadvantage of this approach is that, in practice, contractors may decide against recycling and valuable materials may therefore not be utilized. Furthermore, it may be difficult to compare the conventional and recycling alternatives, not only from a cost point of view, but also with regard to their structural capacities.

Specifying recycling but allowing conventional alternatives

The argument in favour of this approach is that if recycling seems to be feasible, both from a technical and an economic point of view, then road authorities should specify it. Although contractors may be allowed to submit alternatives, and thus be innovative, various measures can be used to encourage recycling: for example, specifying a relatively low maximum proportion of reclaimed material, or requiring a contractor who chooses not to recycle to assume ownership of removed asphalt and to dispose of that proportion of the material which could have been used in a recycled mix at his own cost. Although such a contractor may still incorporate the cost of disposal under another item, his tender price should, at least theoretically, be higher.

By adopting this approach, road authorities will show a clear preference for and commitment to the rehabilitation technique. Contractors may then expect future recycling projects and may therefore be more willing to invest in new equipment. On the other hand, contractors who do not have the ability to recycle may still submit alternative tenders based on conventional techniques.

Many alternatives are, however, likely to complicate specifications, schedules of quantities, and especially the adjudication of tenders, since it may be difficult to determine whether an alternative will give equivalent quality and service life. One way to overcome this problem is to specify recycling as well as the most suitable conventional method. Contractors are then asked to submit tenders for one or both construction methods (22)(33).

Specifying recycling without the option of alternatives

Experience in South Africa and overseas has shown that contractors usually choose not to recycle. Reasons for this may include the perceived complexity of recycling operations, uncertainty regarding possible cost savings, the perceived risk involved, lack of experience, the investment required to gear up for recycling, and a limited number of possible future recycling projects.

The main argument in favour of the specification of recycling without the option of alternatives is that road authorities ought to be the main beneficiaries of recycling operations which use substantial quantities of their existing pavement material. They should therefore take the initiative and specify recycling if they view it to be technically and economically feasible. Furthermore, it is argued that the consultant together with the client should decide how to build or rehabilitate a road, and not the contractor; design responsibility should not be forced onto the contractor.

Disadvantages of specifying recycling without the option of alternatives include stifling innovation and excluding contractors who are unable to recycle. Furthermore it raises the question of whether the responsibility for quality can be defined clearly.

8.1.3 Ownership of reclaimed material

Existing pavements (except for private and/or toll roads), belong to road authorities who represent the

public, and pavement materials removed from these are also public property unless ownership is transferred to the contractor through the contract document. Whether a road authority retains possession of the material or transfers ownership to the contractor should depend on whether recycling is specified as the appropriate rehabilitation technique or not. It may also be influenced by the availability of reclaimed material: that is, whether there is a surplus or a shortage.

Where recycling is an open option, ownership may be transferred to the contractor. If he/she chooses to recycle, then he should assume the responsibility of adopting the required reclaiming, stockpiling, and reprocessing practices to safeguard the integrity of the reclaimed material and hence the recycled mix (12). (This approach is in line with the procedure followed for the supply and quality control of new materials.)

If the contractor decides not to recycle, it can be argued (32) that, if the reclaimed asphalt is economically valuable and there is a competitive marketplace, then the value of this material to the contractor could well be reflected in his/her bid for removal, hauling and eventual re-use or disposal. Theoretically, if the value of the material increases substantially in the future, a contractor could possibly remove and dispose of existing asphalt at no cost or possibly even pay the road authority for assuming ownership.

Where recycling is specified as the rehabilitation technique to be used, it may be preferable for the road authority to retain ownership of the existing asphalt, as more effective control can probably be exercised over the use of the material. However, provision will have to be made for the removal of excess or waste material after the completion of the contract. The contractor could, for example, be required to bid for all reclaimed material not used on the project. If his/her bid is successful, the material then becomes his property. The salvage value bid by the contractor could be subtracted from the total bid price if it is positive, or added if it is negative (22).

On the other hand, ownership can still be transferred to the contractor even if recycling is specified. The contract documents can make provision for the occurrence of unnecessary waste of reclaimed material. The contractor can, for example, be required to incorporate a specified minimum proportion of reclaimed asphalt in the final mix (say 25 per cent). Should he/she fail to do so, because of excessive waste, he could be required to replace said materials at his own cost with new materials of equivalent quality.

Lastly, reclaimed asphalt need not be re-used on the project from which it was removed. The material's economic value can be included in the decision to remove pavement material even if it is intended that the material be used elsewhere. If a road authority has a definite alternative use for all or part of the material, ownership should not be transferred to the contractor.

8.1.4 Prescription of the ratio of reclaimed to new material

The ratio of reclaimed to new material to be used is ultimately a design decision. It should be determined by mix design considerations and not dictated by either the mixing capability of plants or the desire of a road authority to use all the available reclaimed material on a project.

It is considered advisable to allow the contractor reasonable freedom in the selection of the mix design most suited to the circumstances. However, fair adjudication of tenders can be achieved only if contractors all tender on the same basis. The most suitable of the trial mixes, prepared and tested during the preliminary design stage, should therefore be used as the nominal mix for tendering purposes. This approach will

greatly simplify tender adjudication.

Although a predetermined proportion of reclaimed material should not be specified, it may be advisable to specify maximum proportions or both maximum and minimum proportions. If recycling is an open option, the road authority may want to specify upper limits for the proportion of reclaimed asphalt in different pavement layers, to ensure a quality end-product and to reduce the possibility of production problems.

Where recycling is specified, the road authority may also want to specify a minimum proportion of reclaimed asphalt (say 25 per cent) to ensure meaningful recycling. This approach will ensure the use of at least some of the reclaimed material and will give ample opportunity for recycling to develop further.

8.1.5 Provision for variations from the nominal mix

The most suitable mix of preliminary mixes, developed during the project feasibility stage, should be specified as the nominal mix for tendering purposes. However, provision has to be made in the tender document for variations of this nominal mix to allow for alterations once construction has commenced.

Based on varying proportions of reclaimed asphalt (for example, plus or minus 25 per cent in increments of 5 per cent), new aggregate and new binder, allowance can be made for increases or decreases in the price per ton of recycled mix. Alternatively, rates could be required for recycled asphalt with different proportions of reclaimed material (for example, from 20 per cent to 70 per cent), or between the minimum and maximum limits if specified (34). This will allow the mix to be adjusted to satisfy design requirements as the contract progresses and to optimize, if possible, the use of reclaimed material.

The aim should be to ensure that the contractor be paid an equitable rate for the work done and the materials used. It is, however, advisable that the contractor states in his/her tender whether his plant is capable of producing the nominal mix. This is to prevent a contractor from pricing the nominal mix, winning the contract, and then in practice (once he is on site) proving to be more expensive than other tenderers because his plant is unable to produce this mix.

Apart from variations in the ratio of reclaimed to new material, provision should also be made for the following variations:

- the thickness of the existing asphalt layer to be reclaimed;
- reclaimed material properties; and
- the type of new bitumen or additive to be used.

8.2 THE TENDER DOCUMENT – SPECIFICATIONS

In general, project specifications should provide for, amongst others, the following:

- appropriate use of statistical concepts for sampling, process control and acceptance testing
- precise statements of quality requirements and decision criteria
- valid tolerances based on the capabilities of process control and acceptance sampling, as well as on the capabilities of current construction techniques and equipment

- delineation of responsibilities for effective process control to the contractor and acceptance of the completed construction to the client
- valid and fair proportional-payment schedules for non-conforming materials and construction.

Specifications for hot mix recycling operations should be written in such a way that an appropriate balance is also achieved between the following key elements (35):

Accuracy and precision: a clear understanding of the hot mix recycling process is needed to ensure that no undue or unrealistic burdens are placed on the contractor.

Workability: the requirements must be achievable by the methods and equipment available to the industry at the time of project construction.

Suitability: the specification must be geared to the ability of the construction industry to meet the requirements.

Flexibility: this is best achieved through the use of realistic end-product requirements. In this regard, consideration should be given to the development of two sets of specification limits, namely:

- desirable limits, defined as the current specification criteria
- absolute limits, defined in such a way that work falling outside these limits is caused by bad workmanship only.

In this way, work that falls between the desirable and absolute limits owing to, for example, reclaimed material variability, may still, at the discretion of the engineer, qualify for full payment.

Acceptability: the goal is to have an acceptable completed project that fulfills the design requirements.

It is, of course, also necessary to review specifications periodically, so that technological advances in construction, testing and end-product requirements can be taken into account.

Traditionally there have been two main forms of specification each reflecting a different approach or philosophy to the best way of obtaining a quality end-product (36):

- ♦ The so-called end-product specification, emphasises the properties of the finished work, without any regard for the way in which these are obtained. The reasoning is that different methodologies exist and that each contractor will have his/her own most efficient way of obtaining the desired standard. The main advantage of end-product specifications is that they place no restrictions on the contractor's method of working, and thus allow scope for innovative or cost-saving techniques. Furthermore, the checking of workmanship by the engineer is much simplified, as it involves acceptance testing only. The contractor therefore has the responsibility for process/product control.

The disadvantage of end-product requirements is that they have to be specified precisely and unambiguously to ensure that specifications are met and the desired quality maintained. In some cases, end-product specifications and the associated tests for compliance are too sophisticated or time consuming, have not been sufficiently developed, or simply do not exist.

- ◆ The method or recipe-type specification attempts to retain the responsibility for quality in the hands of the designer, by giving the detailed procedures to be used in constructing the works. The disadvantages of this are that the contractor is allowed no latitude, and a heavy responsibility is placed on the designer, since problems may arise if the specified methods are followed and the desired quality does not result.

Experience in South Africa and overseas has shown that it is extremely difficult to monitor and control the quality of a recycled mix based on a broad method specification, as contractually no-one can be held directly responsible for the quality of the product. It is therefore recommended that end-product specifications be used for hot mix recycling operations, supplemented where necessary with method specifications to control, for example, overheating of the binder and the asphalt mix.

Finally, it is suggested that a technical meeting be held during the tender stage with tenderers to explain and/or clarify possible problems related to the project specifications.

In Appendix F aspects of hot mix recycling which may need specification are identified, and guidelines are given where appropriate.

8.3 CONSTRUCTION STAGE

After the tender has been awarded and before construction begins, the recycled mix design should be finalised. To facilitate this, it is recommended that provision be made in the contract documents for the early establishment of the site laboratory, so that the contractor may begin to supplement his/her pre-tender investigations.

The final mix design process follows essentially the same procedure as the laboratory mix design process discussed in sub-section 4.2. However, at this stage, the contractor must provide the designer with asphalt samples reclaimed in the way that will be used during the project, and with aggregate and bitumen samples from the suppliers that he/she intends to use.

Using the final laboratory mix proportions, the contractor may be required to produce the recycled mix and lay a trial section to demonstrate his/her ability to meet specification and normal workmanship requirements.

Three mixes should be produced with the binder content varying from 0,5 per cent above to 0,5 per cent below the laboratory optimum. Asphalt briquettes must be prepared from samples taken at the plant and tested for all the specified properties. Cores obtained from the compacted trial section must be inspected visually and tested for the degree of compaction and standard properties.

Depending on the results of the above, the design of the recycled mix can be finalised and construction can commence. During the construction phase, standard quality control procedures should be followed. Minor modifications to the mix design may be implemented without further trials.

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APPENDIX A

COST SAVINGS MODEL

The total savings that can be expected from undertaking hot mix recycling rather than conventional operations are given by:

$$St = Svm + Sh - Sr + Sm - Sp + Srd + Srs$$

The individual components of this equation can be calculated as follows:

Savings in new material requirements (Svm)

$$Svm = (Qac - Qar)Ca + (Qsc - Qsr)Cs + (Qfc - Qfr)Cf + (Qbc - Qbr)Cb$$

Haulage savings (Sh)

$$Sh = (Qac - Qar)Ha Cha + (Qsc - Qsr)Hs Chs + (Qfc - Qfr)(Hf Chf + Crf) + (Qbc - Qbr)Hb Chb + Qr Hrt Chr^{(1)} - Qrr Hrr Chrm^{(2)} - Qrs Hrs Chrm^{(3)} - Qrt Hrt Chr^{(1)}$$

Notes:

- (1) If removed material is milled rather than ripped and broken, Chrm is substituted for Chr.
- (2) If reclaimed material for recycling is removed after ripping and breaking rather than after milling, Chr is substituted for Chrm.
- (3) If reclaimed material for stockpiling is removed after ripping and breaking rather than after milling, Chr is substituted for Chrm.

Extra costs for reclaiming (Sr)

$$Sr = Qrr (Crm^{(4)} - Cr) + Qrs (Crm^{(5)} - Cr)$$

- (4) If the reclaiming for recycling is accomplished by ripping, breaking and crushing rather than by milling, Crc is substituted for Crm.
- (5) If the reclaimed stockpile is made up of ripped and broken rather than milled material, Cr is substituted for Crm.

Savings in reducing moisture contents (Sm)

$$Sm = (Qac - Qar)Ma Cma + (Qsc - Qsr)Ms Cms - Qrr Mr Cmr$$

Plant modification costs (Sp)

$$Sp = Qm Cpm$$

Removed material disposal fees or revenues (Srd)

$$Srd = (Qr - Qrt)Ct$$

Value of stockpiled reclaimed material (Srs)

$$Srs = Qrs Crs$$

SYMBOLS USED

Quantities	Qm	total mix
	Qac	new aggregate in conventional mix
	Qsc	new sand in conventional mix
	Qfc	new filler in conventional mix
	Qbc	new binder in conventional mix
	Qar	new aggregate in recycled mix
	Qsr	new sand in recycled mix
	Qfr	new filler in recycled mix
	Qbr	new binder in recycled mix
	Qr	removed material
	Qrr	reclaimed material for recycling
	Qrs	reclaimed material for stockpiling
	Qrt	reclaimed material to tip
Haulage distances	Ha	new aggregate
	Hs	new sand
	Hf	new filler
	Hb	new binder
	Hrt	removed material to tip
	Hrr	reclaimed material to recycling plant
Moisture contents	Hrs	reclaimed material to stockpile
	Ma	new aggregate
	Ms	new sand
Unit costs	Mr	reclaimed material
	Ca	new aggregate
	Cs	new sand
	Cf	new filler
	Cb	new binder
	Crs	reclaimed material in stockpile (value of)
	Ct	tipping (or value of disposal revenue)
	Cr	existing material removal (ripping, breaking and loading)
	Crm	material reclaiming by milling
	Crc	material reclaiming by crushing
	Cha	aggregate haulage
	Chs	sand haulage
	Chf	filler haulage
	Chb	binder haulage
	Chr	removed material haulage (ripped and broken)
	Chrm	milled material haulage
	Cma	reducing moisture in new aggregate
	Cms	reducing moisture in new sand
	Cmr	reducing moisture in reclaimed material
	Cpm	plant modification
	Cr _f	rail carriage of filler

Source: Servas and Curtayne (10)

APPENDIX B

APPLICATION OF DECISION THEORY CONCEPTS – AN EXAMPLE

The concepts of decision theory can assist in clarifying the main factors for consideration when a choice has to be made between two rehabilitation options such as recycled and conventional asphalt. These factors are generally the respective cost of each option, their possible outcomes and the probability of each outcome.

Example

The cost savings model predicts that using recycled material is 20 per cent cheaper than the equivalent conventional material. (This, of course, could also have been established from actual tender prices). The durability of both materials is expressed as the probability of failure after eight years. For the recycled product this is taken to be 25 per cent (because of the inherent risk involved in recycling operations) and for the conventional product 10 per cent. In each case failure requires milling off the surfacing and replacing it with a new asphalt layer. Assume a discount rate of 8 per cent. The various estimated costs for this hypothetical case are as follows:

- Placing of recycled asphalt: R 40 000 per km
- Placing of conventional asphalt: R 50 000 per km
- Milling and replacing with new mix after 8 years: R 50 000 per km

These values are shown in Figure B.1. This representation sets out the salient factors in their correct perspective and therefore allows more rational decision-making. Using decision theory, the choice of mix can be based on expected costs. For each option this is given as

$$E_i = C_i + dP_jQ_j$$

where	E_i	=	expected cost of option i
	C_i	=	initial construction cost of option i
	d	=	discount factor
		=	$(1+r)^{-n}$ for discount rate r at time n years from now
	P_j	=	probability of outcome j for option i
	Q_j	=	cost of outcome j

Using this equation the expected cost of the recycling option is

$$\begin{aligned} E_r &= 40\,000 + (1+0,08)^{-8} (0,25)(50\,000) \\ &= R\,46\,753 \text{ per km} \end{aligned}$$

Similarly, the cost of the conventional option is

$$\begin{aligned} E_c &= 50\,000 + (1+0,08)^{-8} (0,10)(50\,000) \\ &= R\,52\,701 \text{ per km} \end{aligned}$$

In this example, recycling is shown to be the cheaper option. Note, however, that if a higher risk of failure

was considered for recycling, the conventional option might have proved to be the cheaper.

Since the probabilities of failure for the two options are based mainly on subjective judgements, it is advisable to repeat the above calculations for a range of probabilities to determine how sensitive a particular option is to a change in the probabilities of failure. For this sensitivity analysis at least three estimates of the probability of failure for each option should be used: the most likely, a pessimistic and an optimistic estimate. Such an analysis will put the various expected costs into perspective and will provide a better basis for decision-making.

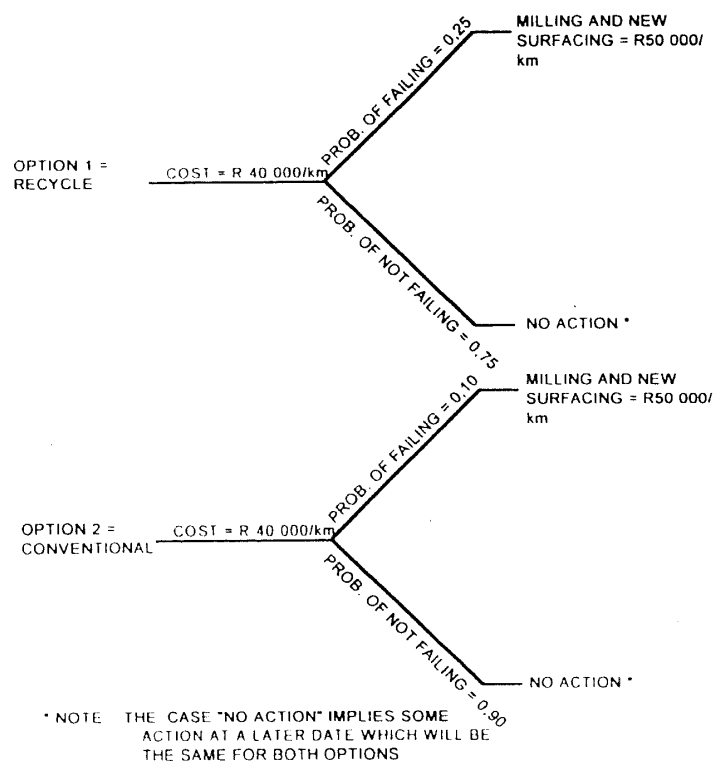


FIGURE B.1: DECISION ANALYSIS DIAGRAMS FOR THE CHOICE BETWEEN RECYCLED AND CONVENTIONAL MIXES

Source: Adapted from Servas and Curtayne (10)

APPENDIX C

FLORIDA DEPARTMENT OF TRANSPORTATION GRADATION ADJUSTMENT METHOD FOR THE EFFECT OF MILLING OPERATIONS

The purpose of this procedure is to adjust the grading of the existing asphalt to provide an estimate of the resultant grading after milling.

Method

Determine the total percentage material retained on the 13,2 mm sieve. Multiply this value by 0,5 and sequentially add this percentage to the percentage passing for aggregate sizes down to the 2,36 mm sieve. Also increase the percentage passing the 0,075 mm sieve by approximately 3 to 7 per cent. Adjust the percentage passing the remaining sieves (ie 1,18 mm, 0,6 mm, 0,3 mm and 0,15 mm) by 50 to 100 per cent of the amount used to increase the percentage passing the 0,075 mm sieve. An example of this procedure is presented in Table C.1.

Note

Caution should be exercised in the use of these adjustment factors since they are based on the results obtained from only two projects. Furthermore, it can be expected that different factors will be needed for different types of asphalt. It is recommended that practitioners develop their own factors based on previous and future experience.

TABLE C.1: EXAMPLE OF GRADATION ADJUSTMENT TO ESTIMATE MILLED ASPHALT GRADATION

SIEVE SIZE (MM)	GRADING OF EXISTING ASPHALT (CUM. % PASSING)	CORRECTION FACTOR (%)	ESTIMATED GRADING OF MILLED ASPHALT
26,5	100	+ 8	100
19,0	94	+ 8	100
13,2	84 *	+ 8	92
9,5	70	+ 8	78
6,7	58	+ 8	66
4,75	48	+ 8	56
2,36	36	+ 8	44
1,18	28	+ 4 ***	32
0,60	23	+ 4	27
0,30	15	+ 4	19
0,15	8	+ 4	12
0,075	4	+ 5 **	9

* $(100 - 84) \cdot 0,5 = 8 \%$ ** Decide on value between 3 % and 7 %

*** 50 % to 100 % of correction factor for 0,075 mm sieve; in this case 80 % was chosen

Source: Adapted from the Florida Department of Transportation (13)

APPENDIX D

SUMMARY OF MIX DESIGN PROCEDURE AND ACCOMPANYING COMPUTATIONAL PROCEDURES

1. Obtain representative samples of asphalt to be recycled.
2. Analyse reclaimed asphalt
 - binder content
 - recovered binder penetration/viscosity
 - recovered aggregate grading.
3. Establish the grading specification for the final mix.
4. Obtain gradings of available new aggregate.
5. Determine the most suitable proportion and grading of new aggregate.
6. Determine the optimum binder content through a Marshall mix design, using a standard penetration/road grade binder.
7. Determine the percentage of new binder required in the recycled mix.
8. Determine the penetration/viscosity of the new binder.
9. Repeat the Marshall mix design process using the determined proportions of reclaimed asphalt, new aggregate and new binder, and adjust if necessary.

EXAMPLE OF COMPUTATIONAL PROCEDURES (for one ton of recycled mix)

1. Data from analysis of reclaimed asphalt:

BCR = binder content by weight of reclaimed asphalt sample
= 0,055 (5,5%)
2. Data from grading design:

NA = new aggregate in recycled mix, percent by weight of total mix
= 0,365 (36,5%)

RA = reclaimed aggregate, percent by weight of total mix
= 0,570 (57,0%)
3. Data from preliminary Marshall mix design:

BCF = binder content of recycled mix, percent by weight of total mix
= 0,065 (6,5%)

NOTE: BCF + RA + NA = 1 (or 100 if in percentages) for preliminary mix design.

4. Compute amount of reclaimed asphalt (RAP) per ton of mix:

$$RA = RAP - (BCR)(RAP), \text{ or}$$

$$RAP = \frac{RA}{1 - BCR}$$

$$= \frac{0,570}{1 - 0,055}$$

$$= 0,603 (60,3\%)$$

5. Compute new binder (BCN) requirements:

$$\begin{aligned}\text{BCN} &= \text{BCF} - (\text{BCR})(\text{RAP}) \\ &= 0,065 - (0,055)(0,603) \\ &= 0,032 \quad (3,2\%)\end{aligned}$$

6. Summary of laboratory mix design:

$$\begin{aligned}\text{RAP} &= 0,603 \text{ ton/ton recycled mix} \\ \text{NA} &= 0,365 \text{ ton/ton recycled mix} \\ \text{BCN} &= 0,032 \text{ ton/ton recycled mix}\end{aligned}$$

APPENDIX E

GUIDELINES FOR THE SELECTION OF THE APPROPRIATE RECLAIMING TECHNIQUE

The factors influencing the choice of particular reclaiming techniques are summarized below. These factors, however, should not be considered in isolation as many cross-influences exist. Nevertheless, the checklist should facilitate selecting the most appropriate technique.

INFLUENCING FACTOR	COMMENT	
	RIPPING AND CRUSHING	COLD MILLING
Nature of subsequent work: - hot mix recycling - cold mix recycling - reuse of existing asphalt as substitute - reuse of existing asphalt on project not considered	Consider cost effectiveness and relevant influencing factors. Double handling required for off-site crushing. Double handling required if crushing is needed to achieve grading. Usually cheaper as crushing is not needed unless alternate uses (on other projects) can be found.	Consider cost effectiveness and relevant influencing factors. Milled material can be left in situ or windrowed for processing. Can be placed directly. Less advantageous if not used immediately as double handling would be required for temporary stockpiling. Milled material easier to market. Also leaves good working platform with uniform levels for subsequent work.
Timing of repaving with recycled mix: - soon (short term) - later (medium to long term)	Review cost effectiveness and relevant influencing factors. Integrity of reclaimed binder is better protected if stockpiled without crushing. Stockpile less vulnerable to theft.	Review cost effectiveness and relevant influencing factors. Quality of the reclaimed binder likely to deteriorate through oxidation and hardening. Material also likely to congeal, thereby defeating the milling process.
Economics	Usual cheaper in terms of direct costs. Cost effectiveness depends on many factors including haul distances (low bulk density of ripped material), traffic disruption, reclaimed material quality and damage to underlying layers.	Usually more expensive in terms of direct costs. Cost effectiveness - as for ripping and crushing.
Availability of equipment	Variety of equipment more readily available. Simple process.	Restricted to specialized and expensive machinery. Skilled operators required.
Traffic disruption	Very disruptive.	Less disruptive, especially in urban areas. Leaves a trafficable surface.

INFLUENCING FACTOR	COMMENT	
	RIPPING AND CRUSHING	COLD MILLING
Effect on grading of reclaimed asphalt	Better control with crushing. Less generation of fines and loss of binder through dust, if crusher is properly adjusted and operated.	Loss of some existing binder through dust during milling and loading, especially in windy conditions. Change of grading dependent on condition and type of existing asphalt, and characteristics and operation of milling machine.
Contamination of asphalt with underlying material	Higher risk of contamination - not easily controlled and underlying layer often disturbed.	Milling depth can be accurately controlled and contamination generally not a problem.
Selective lane removal	Longitudinal and transverse joints require saw-cutting and careful protection of adjoining edges - expensive.	Versatile removal to selected widths and depths. Easy to construct joints.
Reclaiming under wet conditions	Reduced exposed area - less sensitive to wet weather.	Milled material usually highly absorbent, leading to variable moisture contents of stockpiles.
Asphalt removal from bridge decks	Restricted to hand operated pneumatic breakers and cutting equipment.	Less risk of damage to structure.
Uniformity of existing asphalt	Suitable if material is uniform; otherwise use only in low proportions.	Easy separation of different layers, both in depth and area.
Treatment of underlying layers: - no treatment required except for possible application of prime or tack coat - in-place treatment, eg stabilization - excavation to spoil or stockpile	 Underlying layers likely to be unacceptably disturbed requiring reprofiling and recompaction to restore the surface and density. Some loss of underlying material by ripping and loading. Not affecting by ripping, hence consider cost effectiveness and other influencing factors.	 Minimal disturbance of underlying layers and provides a good platform for subsequent work. Thin residue of existing asphalt left in place after milling usually not detrimental if worked into underlying layer. Consider cost effectiveness and relevant influencing factors.
Quality of existing asphalt: - aged but basically sound - severely cracked - binder stripped	 Consider cost effectiveness and relevant influencing factors. Better grading achieved by crushing. More economical if material cannot be reused.	 Consider cost effectiveness and relevant influencing factors. Likelihood of oversize material being lifted but not milled. Expensive if material is likely to be spoiled.
Speed of operation	Overall reclamation process relatively slow.	Material ready to be recycled.

APPENDIX F SPECIFICATIONS: SCOPE AND GUIDELINES

This appendix identifies areas where specifications may be required for hot mix recycling operations and provides guidelines where appropriate. It is divided into three main sections:

- Asphalt reclaiming
- Stockpiling of reclaimed material
- Production of the recycled mix

Note: Guide specification values marked with an asterisk (*) were obtained from the CSRA Series 4000 Standard and Project Specifications (31).

ASPHALT RECLAIMING

The quality and integrity of the reclaimed material determines to a large degree the quality of the recycled mix and hence the success of the recycling operation. This quality depends largely on the asphalt reclamation and stockpiling processes. Proper control over reclaiming operations and the stockpiling of reclaimed asphalt can therefore contribute markedly towards ensuring a high-quality end-product.

Items or aspects that may have to be considered in preparing a specification for asphalt reclaiming are given in Table F.1 below, with guideline values where appropriate.

It is assumed that asphalt reclamation will be done by a milling machine. No special requirements are needed if conventional ripping equipment is used, unless damage to underlying and adjacent layers is not permitted. The use of saw-cutting and crushing equipment may, however, need special consideration.

TABLE F.1: ASPHALT RECLAIMING

ITEM / ASPECT	GUIDE SPECIFICATION
Equipment – milling machine	
(a) range of milling depths	(a) 10 mm to 150 mm * in one pass; (100 mm max depth may be more practical)
(b) range of milling widths	(b) 1,5 m to 4,0 m*; widths smaller than 1,5 m may be more suitable for patching operations
(c) grade and slope control	(c) automatic
(d) depth of milling control	(d) electronically; milling depth tolerance: 5 mm or 10% of the milling depth with a maximum of 15 mm
(e) milling drum	(e) adjustable direction of rotation and rotation speed
(f) machine speed	(f) adjustable: 1,5 to 15 m per min
(g) conveyor	(g) adjustable for offset or in-line truck loading

ITEM / ASPECT	GUIDE SPECIFICATION
Construction	
(a) mixing or contamination of existing asphalt with material from other layers	(a) to be minimized; allowable limits to be defined
(b) damage to underlying layers	(b) to be repaired at own cost
(c) working platform produced by the milling operation	(c) must be even and level with a uniform texture
(d) surface deviation after milling	(d) should not, in any direction, exceed 7 mm over a 3 m length *
(e) surface area covered by bituminous material after milling	(e) not more than 5% *; practical considerations may require different limits to be specified
(f) cleaning of exposed surface	(f) brooming and cleaning with compressed air prior to repaving
(g) maximum size of milled material	(g) 26,5 mm*; or 100% passing 37,5 mm and 90% passing 26,5 mm; or as approved by the engineer
(h) oversized material	(h) to be defined and screened out accordingly
(i) specified milling width	(i) not to be exceeded by more than 50 mm*
(j) damage to layers outside specified width	(j) to be repaired at own cost
(k) spraying of water during milling to cool cutting tools and to control dust	(k) should not exceed 5 litre per ton of reclaimed material
(l) maximum vertical deviation between two adjoining surfaces	(l) not to exceed 30 mm
(m) milling during wet weather	(m) not allowed
(n) trial milling	(n) may be required to demonstrate ability to achieve specified grading
(o) separate reclaiming of different types of asphalt layers	(o) may be required
(p) length of milled but unprocessed section of road	(p) a maximum length may be specified to prevent unlimited lengths of exposed layers open to damage by rain
(q) milling within a confined area	(q) special drainage measures to drain the milled box after or during rainstorms may be required

Measurement and payment

Rates, per cubic metre of material milled, should be provided in the specifications for different depths of milling; for example, 10 to 30 mm, 30 to 60 mm and more than 60 mm. Measurements should be taken in situ before milling.

STOCKPILING OF RECLAIMED MATERIAL

The aspects to be considered for specification are given in Table F.2.

TABLE F.2: STOCKPILING OF RECLAIMED ASPHALT

ITEM / ASPECT	GUIDE SPECIFICATION
(a) stockpiling site	(a) must be clean - all organic and other foreign matter must be removed (prevention of contamination)
(b) site surface area	(b) must be well compacted (90% mod AASHTO) *; stabilisation up to 150 mm may be required *
(c) location of site	(c) not near a crusher, concrete batching plant or gravel road (to prevent contamination)
(d) drainage of the site	(d) surface graded to a free draining profile
(e) stockpiling of different types of reclaimed asphalt	(e) separately, without overlapping
(f) size and slope of stockpiles	(f) such that segregation and consolidation are prevented (large conical shapes to be avoided)
(g) height of stockpiles	(g) not to exceed 3 m
(h) covering of stockpiles	(h) may be required
(i) equipment used to stockpile	(i) such that consolidation and segregation are prevented
(j) consolidated material	(j) to be broken up and screened if necessary; may be at own cost, depending on cause
(k) recording of asphalt in stockpiles	(k) in terms of grading, binder content, recovered binder penetration and moisture content
(l) sampling of stockpiles	(l) standard sampling procedures
(m) frequency of sampling/testing	(m) depends on material uniformity; at least 1 sample per 200 tons for grading and binder content; 1 sample per 500 tons for recovered binder penetration
(n) removal of material from stockpiles	(n) across the stockpile face; not by point-loading
(o) remixing of stockpiles	(o) may be required if test results prove to be highly variable
(p) storage/stockpile period of milled asphalt	(p) not more than 3 months (to prevent consolidation and ageing, and possibly invalidating the mix design), unless otherwise specified

PRODUCTION OF THE RECYCLED MIX

Items to be taken into consideration regarding the production of recycled mixes are given in Table F.3.

TABLE F.3: RECYCLED MIX PRODUCTION

ITEM / ASPECT	GUIDE SPECIFICATION
Materials	
(a) reclaimed asphalt uniformity	(a) should be uniform and within specified variability limits of grading, binder content and recovered penetration/viscosity; free of contamination; not segregated; maximum size - as specified
(b) screening of reclaimed asphalt	(b) may be required to remove oversized materials
(c) reclaimed material containing tar	(c) not to be used for recycling
(d) quantities of reclaimed material	(d) determined in accordance with fixed quantities excavated and accepted; allowance must be made for normal waste
(e) waste of reclaimed asphalt	(e) unnecessary waste to be made up at own cost by equivalent new materials
(f) new binder and new aggregate	(f) conform to standard specifications
(g) penetration/viscosity of the new binder	(g) to be decided on after final mix design has been done; should be such that the final recovered penetration/viscosity requirement for the recycled mix is met
(h) grading of the new aggregate	(h) such that the combined grading (reclaimed and new aggregate) conforms to the approved grading for the final mix
(i) samples of materials to be used	(i) to be submitted to the engineer in good time prior to the production
Mix composition and characteristics	
(a) mix composition to be used	(a) must be determined by the contractor through an approved laboratory; to be submitted to the engineer at least 8 weeks prior to production *
(b) nominal mix proportions for tendering	(b) as specified
(c) variations from nominal mix proportions	(c) provision has to be made
(d) minimum and maximum proportions of reclaimed asphalt	(d) may be specified
(e) failure to incorporate the minimum proportion reclaimed asphalt in the mix (if specified)	(e) operations may continue upon approval of the engineer; payment may be only for that amount of material required to produce an acceptable mix at not less than the minimum % of reclaimed asphalt specified

ITEM / ASPECT	GUIDE SPECIFICATION
(f) reclaimed material not incorporated in new work	(f) shall become the property of the contractor unless otherwise specified
(g) the recycled mix should conform to the normal requirements for conventional mixes; if deemed appropriate, standard specifications could be modified to provide a project specification; normal requirements include : - grading - binder content, ductility and softening point - mix properties - moisture content - air voids and VMA	(g) - as specified in project specifications; reasonable non-conformity may be allowed at the discretion of the engineer - as specified - as specified for the particular type of mix - not to exceed 1,0% by weight or as specified - as specified
(h) special requirement: minimum recovered binder penetration	(h) wearing course: 30 or 35 base course: 30 subbase (under concrete): 25
(i) allowable tolerances: - binder content - grading - air voids	(i) - plus or minus 0,3% *; this may be too narrow for recycled mixes; consideration should be given to the widening of the limits, say to 0,4 or 0,5%, calculated on a statistical basis using the variance of the reclaimed asphalt binder content - allowable deviation, if any, outside the grading envelope to be defined - plus or minus 1,5% or as specified
Equipment	
(a) type of mixing plant	(a) approved batch plants or drum mixers, properly modified or built specially for recycling
(b) plant requirements - general	(b) - able to produce both recycled and conventional mixes - so equipped that the measurement, heating and mixing of the various materials will result in a uniform mix

ITEM / ASPECT	GUIDE SPECIFICATION
(c) air pollution	(c) in accordance with local requirements
(d) surge bin capacity	(d) a minimum of 70 tons
(e) aggregate feed	(e) - means for accurate calibration of both reclaimed material and new aggregate - for each aggregate, a separate feeder is required, able to maintain a positive, continuous feed - the aggregate feeding system must be interlocked with the new binder feed - conveyors must be equipped with a continuous weighing system
(f) binder feed	(f) positive control of the new binder feed automatically coupled with the aggregate feed, and able to maintain a uniform rate of delivery
(g) heating and mixing	(g) - satisfactory protection of the reclaimed asphalt from the open flame of the burner - plant must be able to heat the resultant mix to the specified discharge temperature; the temperature and mixing time must be controlled to prevent damage to the binder
Production and acceptance	
(a) production method	(a) details to be presented to the engineer at least 4 weeks prior to production *; a broad outline of proposed method to be submitted with tender for evaluation
(b) breakdown of reclaimed asphalt to original maximum size aggregate	(b) to be achieved by the heating and mixing process to give an intimate mix of old and new materials
(c) mixing times	(c) to be controlled to deliver the specified product without damage to the binder
(d) mix temperature at discharge	(d) 140 to 160 degrees Celsius
(e) storage time in surge bin	(e) not to exceed specification
(f) process/end-product control	(f) to be done by the contractor
(g) acceptance testing	(g) to be done by the engineer, to ensure that the recycled mix complies with the mix specifications
(h) point of acceptance sampling	(h) plant discharge or paver; to be specified
(i) frequency of acceptance testing	(i) to be specified
(j) price adjustments for out-of-specification mixes	(j) to be specified, using appropriate tolerance limits

ITEM / ASPECT	GUIDE SPECIFICATION
(k) trial sections	(k) the contractor may be required to lay a trial section to demonstrate his ability to meet specification and normal workmanship requirements
Construction	
(a) paving operations	(a) adhere to standard specifications for paving
(b) minimum surface temperature	(b) to be specified
(c) requirements and allowable tolerances with regard to: - layer thickness - smoothness of surface - density to be achieved	(c) to be specified
(d) acceptance testing	(d) by engineer; frequency to be specified
(e) surplus material	(e) to become the property of the contractor unless otherwise specified
(f) traffic control	(f) in accordance with specifications and local requirements
(g) safety requirements	(g) to be set with regard to maximum vertical transverse and longitudinal deviations between two surfaces at end of workday

Measurement and payment

The unit of measure should be square metres or tons of recycled asphalt.

The bid price must include full compensation for the procurement and delivery of all new materials, the obtaining of reclaimed asphalt from stockpiles, the heating, mixing, placing and compaction of the recycled mix, and for all process control testing.

No payment should be made for increased new material requirements owing to the unnecessary waste of reclaimed asphalt.