CEDR Transnational Road Research Programme
Call 2012: Recycling: Road construction in a post-fossil fuel society

Funded by Denmark, Finland, Germany, Ireland, Netherlands and Norway

AllBack2Pave

AllBack2Pave End-User Manual

Deliverable No D3.1
November 2015

CEDR Call2012:
Recycling: Road construction in a post-fossil fuel society

ALLBACK2PAVE

Toward a sustainable 100% recycling of reclaimed asphalt in road pavements

Deliverable No D3.1
AllBack2Pave End-User Manual

Start date of project: 01.11.2013
End date of project: 30.09.2015

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Version: 05.2015

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List of abbreviations

AC	Asphalt Concrete
Add	Additive
BP	Best Practice
BPl	Batch Plant
BR	Basic Rule
C&F	Crushing and Fractioning
CEDR	Conference of European Directors of Roads
CO	Carbon Monoxide
DAV	German Asphalt Pavement Association
DoD	U.S. Department of Defense
DP	Drum Plant
EAPA	European Asphalt Pavement Association
F	Fractioning
FHWA	Federal Highway Administration
H&WMA	Hot and Warm Mix Asphalt
HMA	Hot Mix Asphalt
HR	Hot Recycling
L&C	Laying and Compaction
LC	Large Chunks
M	Milling
M3S	Multiple Source Separate Stockpile
MA	Mastic Asphalt
NMAS	Nominal Maximum Aggregate Size

NCHRP	National Cooperative Highway Research Program
NOx	Nitrous Oxides
PMB	Polymer Modified Binders
QC	Quality Control
QF(a)	RA available Quantity Factors
QF(p)	RA placed Quantity Factors
R	Regulation
RA	Reclaimed Asphalt
RA Mix T	RA Mix Transportation
RAP	Reclaimed Asphalt Pavement
RA T	RA Transportation
REM	REliability Measure
RR	Reliability Ratio
S	Specification
SABITA	Southern African Bitumen Association
SMA	Stone Mastic Asphalt
SUPERPAVE	SUperior PERforming Asphalt PAVEment
TPM	Total Particulate Matter
UFC	United Facilities Criteria
UFGS	Unified Facilities Guide Specification
VMA	Voids in the Mineral Aggregate
VOC	Volatile Organic Compounds
WMA	Warm Mix Asphalt

WR	Warm Recycling
WV	Weight Value
ΔU	RA Placed Rate
4S	Single Source Separate Stockpile

1 Introduction

Nowadays in Europe the policy of the reuse and the recycling of waste materials encourages the stakeholders to improve the making process of the reclaimed asphalt within road pavements.

In order to assess the technical and economic capacity of recycling of asphalt material over a European scale, official data from the European Asphalt Pavement Association (EAPA) were acquired and then processed in various forms. These data, covering a period from 2006 to 2013, are the last updated available data. It was intended to divide Europe into three major areas as much as possible-homogeneous geographically and culturally: Southern Europe, Central Europe and Northern Europe (Figure 1).

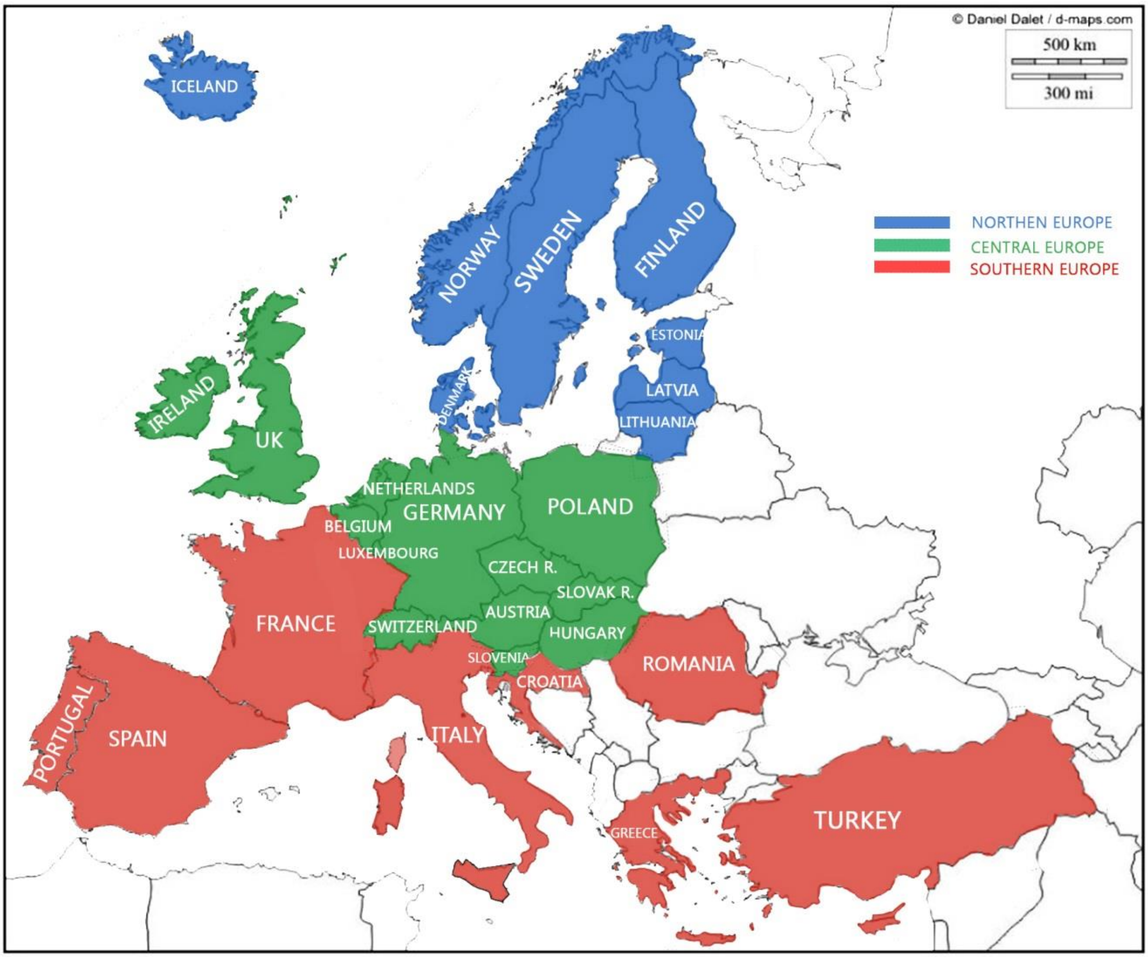

Figure 1: European Areas: south Europe (red countries); middle Europe (green countries); northern Europe (blue countries)

In a first instance it is meaningful to analyse the historical trend (2006-2013) of the production of Hot and Warm Mix Asphalt (H&WMA) (Figure 2).

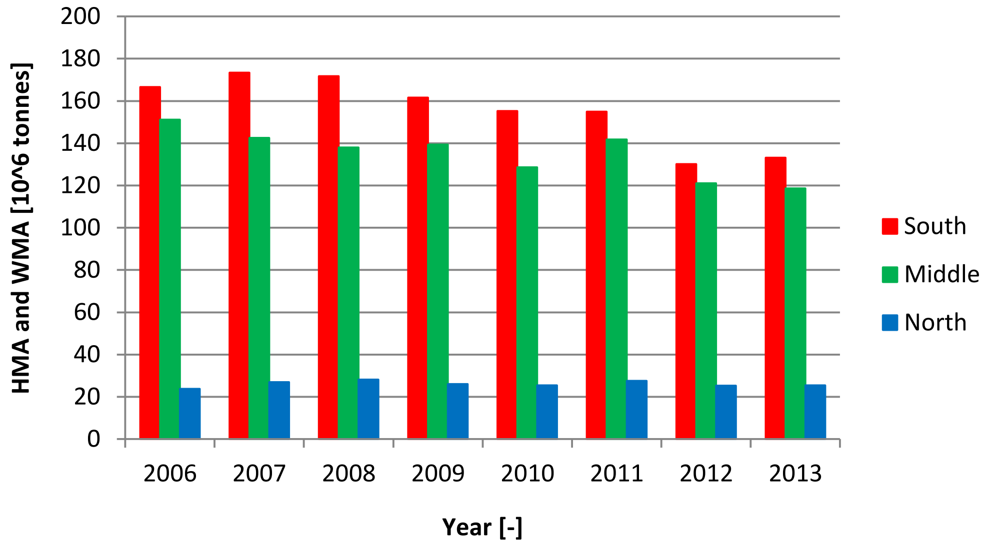

Figure 2: Hot and Warm Mix Asphalt Production in Europe from 2006 to 2013

The historical trends for the countries, which are the major producers of H&WMA to each of the three areas considered, are reported in Figure 3: France for the Southern area (average annual production of approximately 39 million tons), Germany for the Central area (average annual production of approximately 49 million tons), and finally, for the North European area, Sweden (average annual production of about 8 million tonnes). All historical trends are in line with what was previously observed; in relation to French and German productions, we are witnessing to a decrease in production as it happens, in general, in their respective areas. While Sweden has, over the years, a constant trend of production as it is the case in general for North Europe.

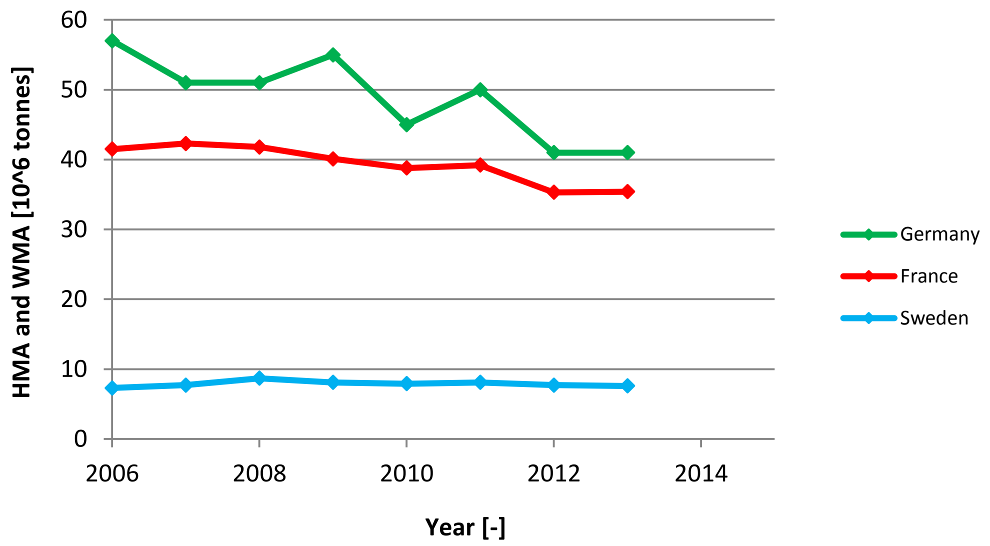

Figure 3: Hot and Warm Mix Asphalt Production in Germany, France and Sweden from 2006 to 2013

Finally, the historical trends for the three countries Germany, United Kingdom and Italy that are part of the research project to which the present work is connected are given in Figure 4.

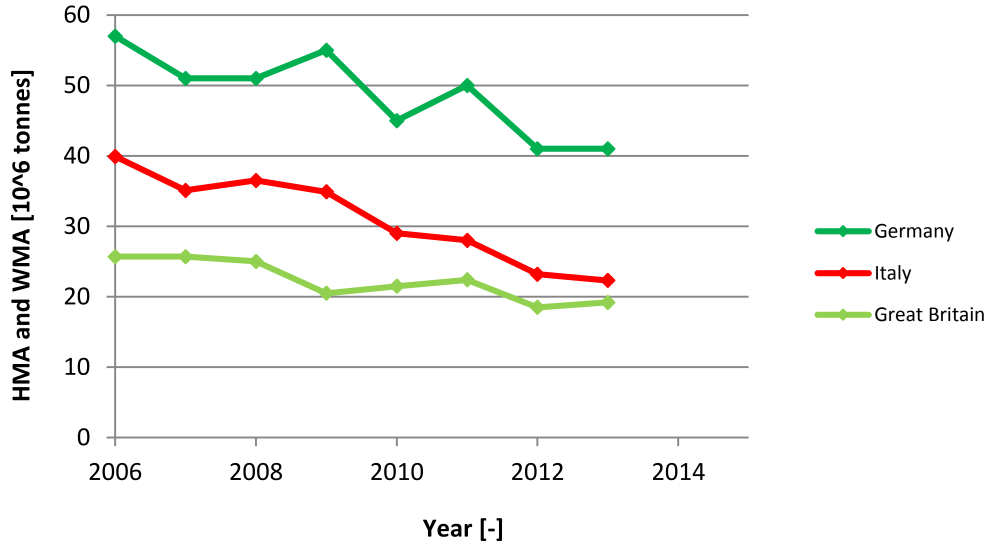

Figure 4: German, Italy and United Kingdom H&WMA Production 2006-2013

As noted previously, the German trend is decreasing as well as the Italian one, which has an average annual production of about 31 million tons of hot and warm asphalt mixes. In United Kingdom also a decreasing production can be observed, having an average annual production equal to about 22 million tons over the period 2006-2013.

The following three histograms (Figure 5, Figure 6 and Figure 7) show the historical development divided by layers for the three European areas. The main production of H&WMA is intended essentially to wearing courses (top layer), while the average asphalt production for base layers is significantly lower.

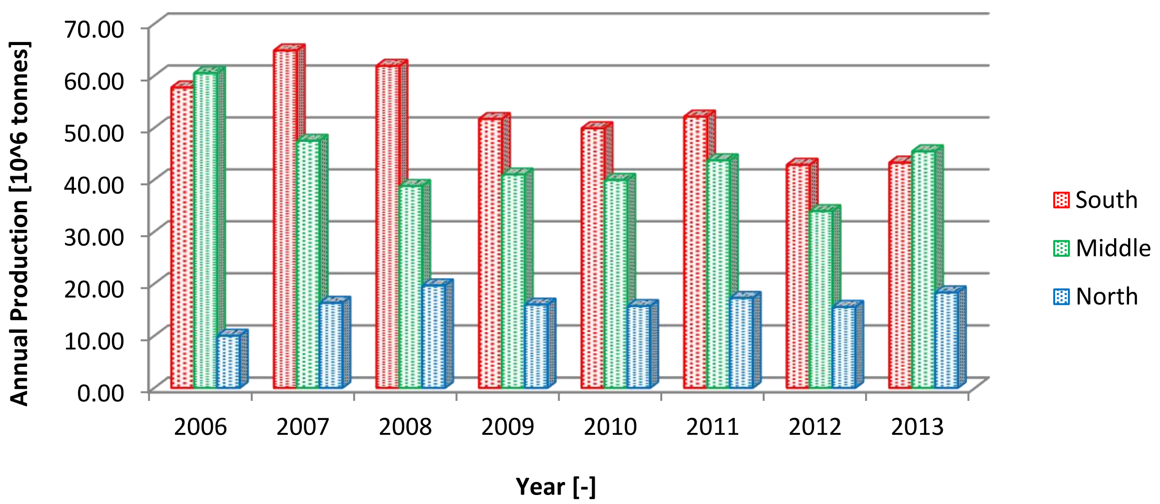

Figure 5: Hot and Warm Mix Asphalt production for wearing course

Compared to the asphalt production for the both upper layers, the reported asphalt production for binder layers is only marginal. It is not superfluous to recall that the thicknesses of typical wearing courses (3-6 cm) is significantly lower than the thickness of typical base layers (8-15 cm). This outcome can be explained by considering that road pavement maintenance and rehabilitation activities are more frequent than paving of new road infrastructures: such activities indeed mainly concern the top layer.

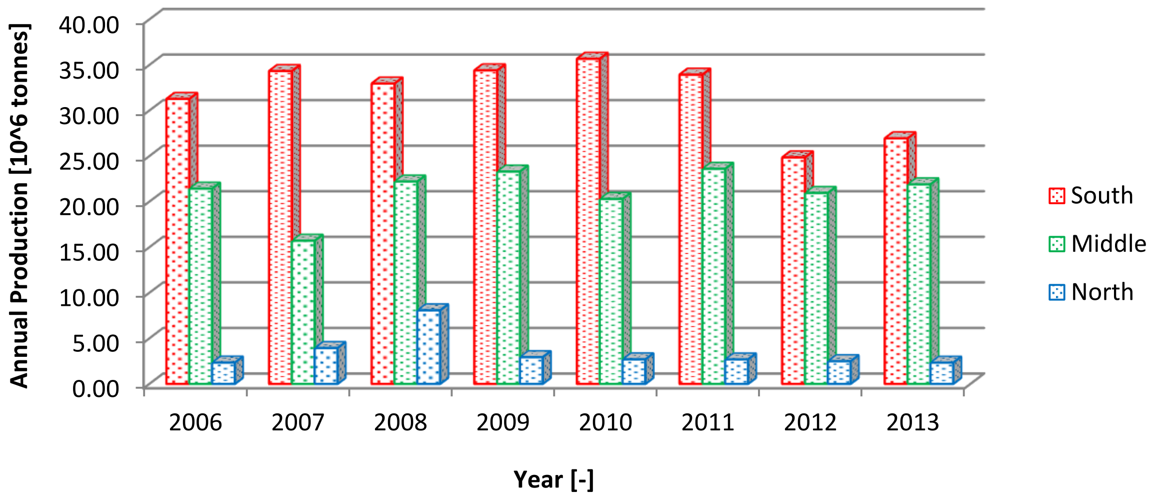

Figure 6: Hot and Warm Mix Asphalt production for binder layer

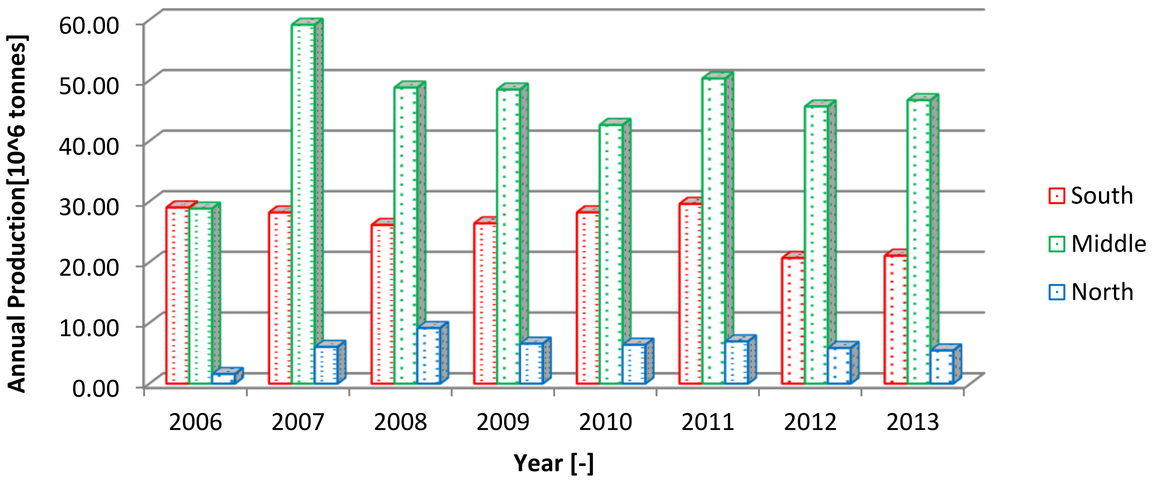

Figure 7: Hot and Warm Mix Asphalt production for base layer

As shown in the following Pie Charts (Figure 8, Figure 9 and Figure 10), the analysis may be carried out taking into account the average annual production of each layer and referring to three European areas, namely the South, the Centre and the North of Europe. It is evident the main production regards the wearing course.

So, as regards the importance of the wearing course asphalt production as shown in following pie charts, the aim of a research about reusing the maximum possible quantity of recycled asphalt (RA) in new asphalt wearing courses fits well with sustainability objectives declared.

Moreover, Figure 11 shows a comparison of the total H&WMA production over eight years (2006-2013), distinguishing for each layer and for geographic area, confirms the above mentioned objective: to encourage the reuse of RA in the production of new asphalt layers, because it exhausts a huge quantity of resources.

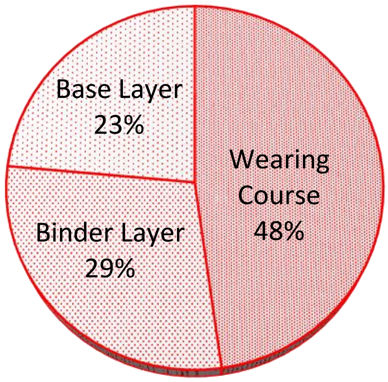

Figure 8: Percentage distribution in South European Area (Average Value over 2006-2013)

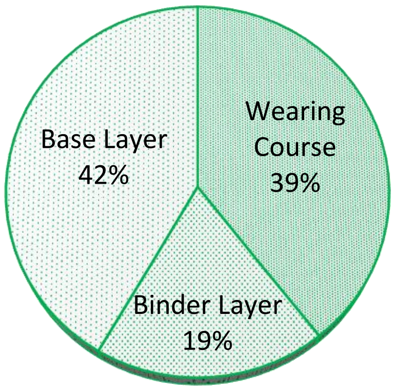

Figure 9: Percentage distribution in Middle European Area (Average Value over 2006-2013)

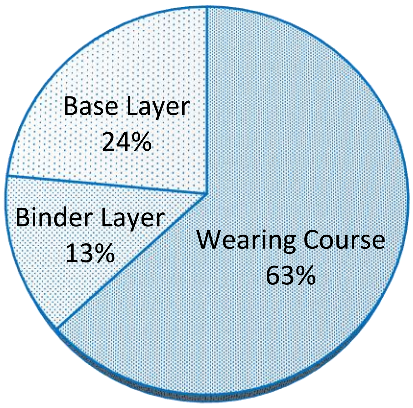

Figure 10: Percentage distribution in North European Area (Average Value over 2006-2013)

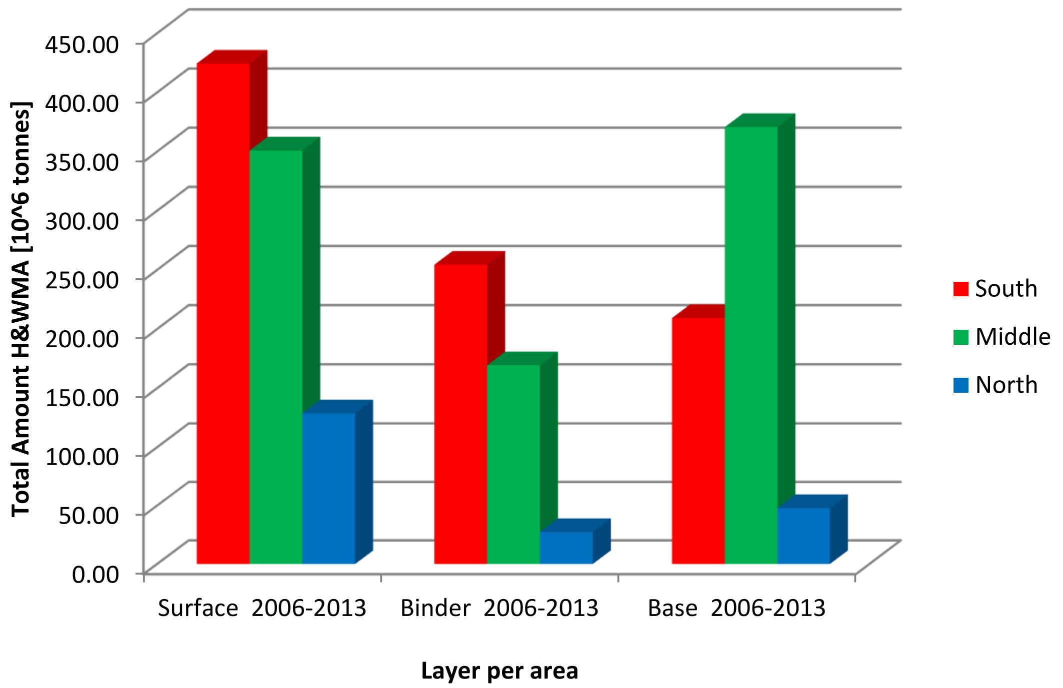

Figure 11: Total production of Hot and Warm Mix Asphalt mixes (Average Value over 2006-2013)

Such analysis provides interesting technical and economic cause for reflection.

Nevertheless it is worth of being underlined that there is a significant deviation between placed Reclaimed Asphalt (reused RA) and available one (stored RA), especially in the "South European" area (Figure 12, Figure 13, and Figure 14).

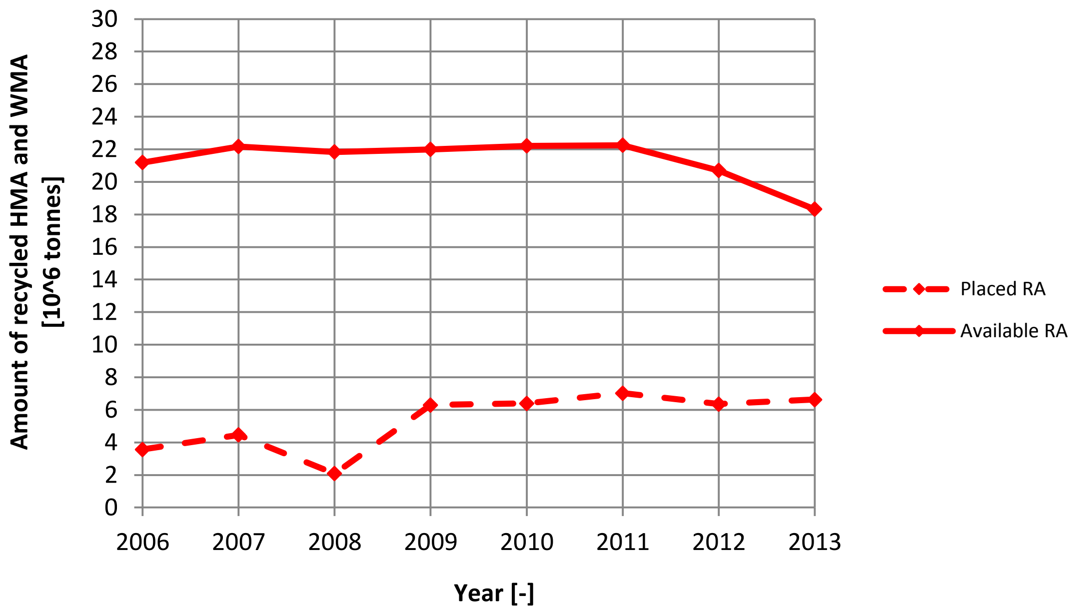

Figure 12: Recycling of Hot and Warm Mix Asphalt mixes in Southern Europe

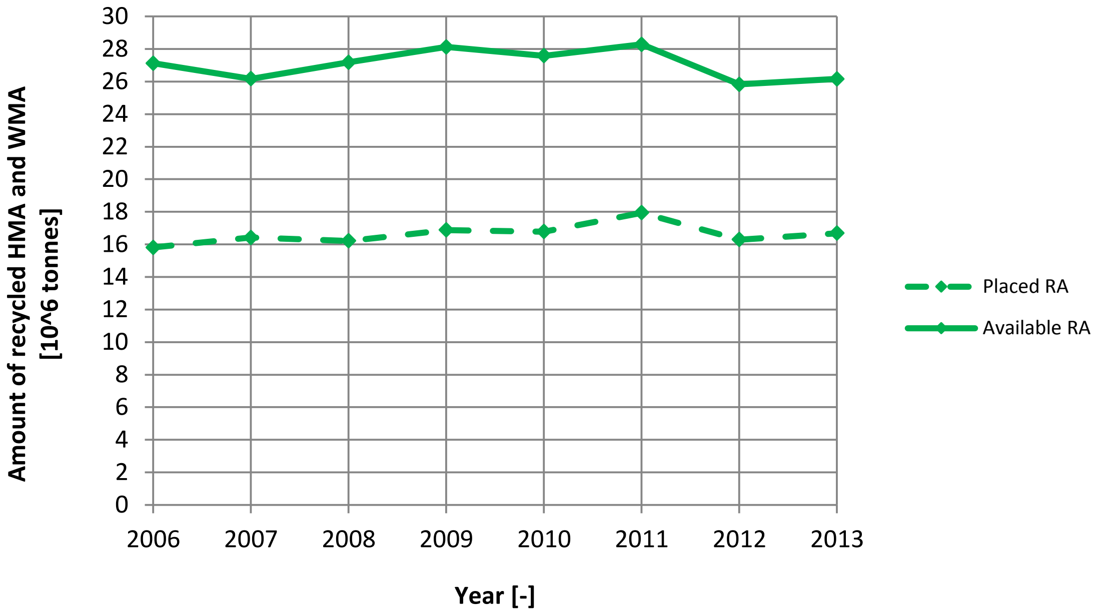

Figure 13: Recycling of Hot and Warm Mix Asphalt mixes in Central Europe

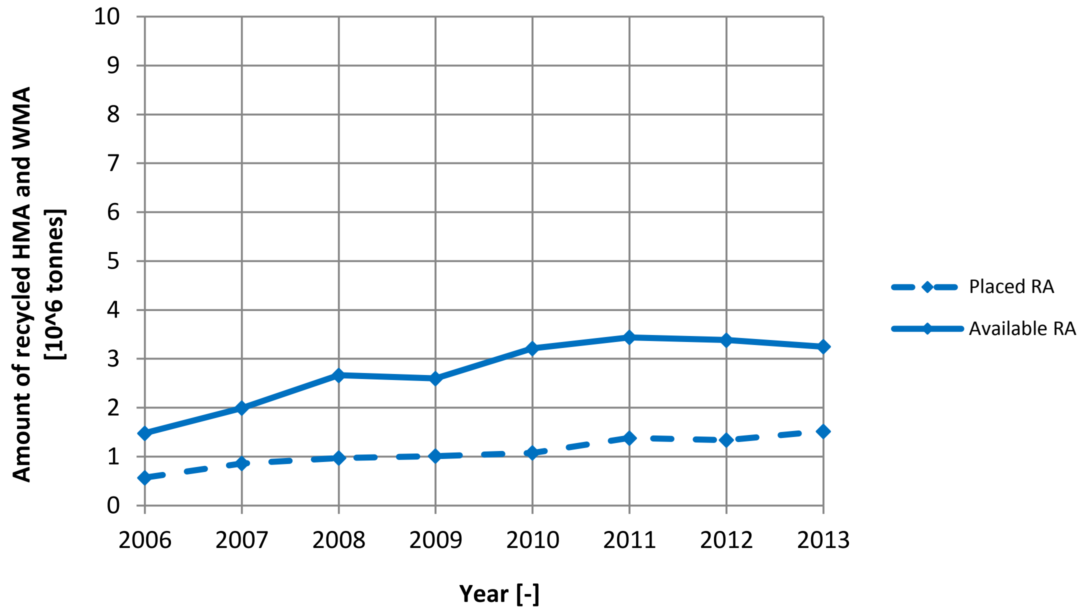

Figure 14: Recycling of Hot and Warm Mix Asphalt mixes in Northern Europe

For the South, Middle and North European parts, according to Figure 1, the “RA Placed Rate” ΔU can be calculated:

$$\Delta U = \frac{RA\ Placed}{RA\ Available} \times 10$$

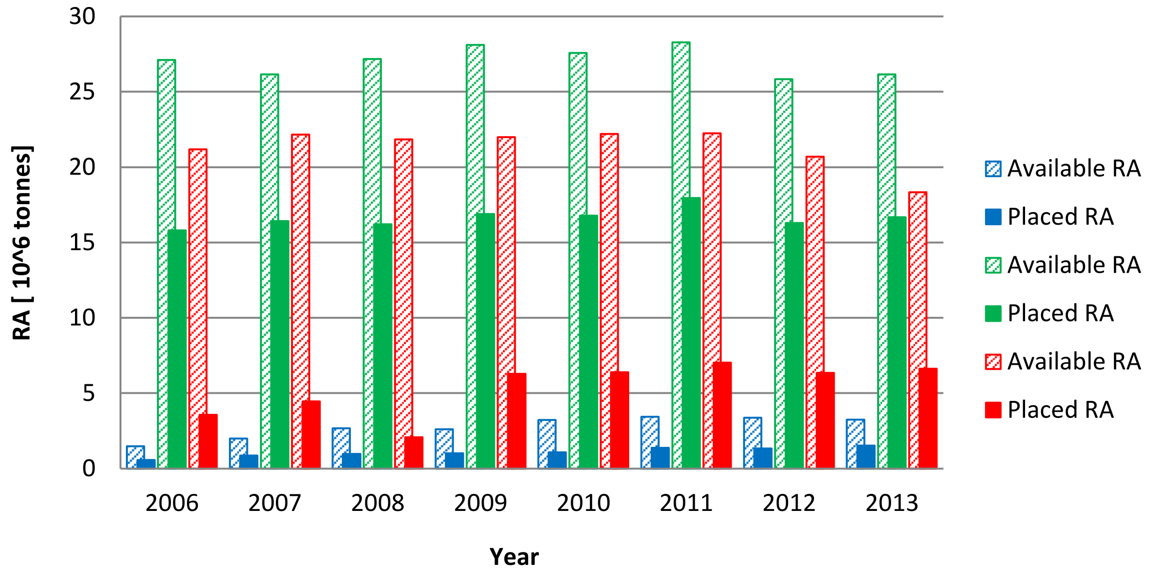

Figure 15: Available and Placed RA for: south Europe (red country); middle Europe (green country); north Europe (blue country)

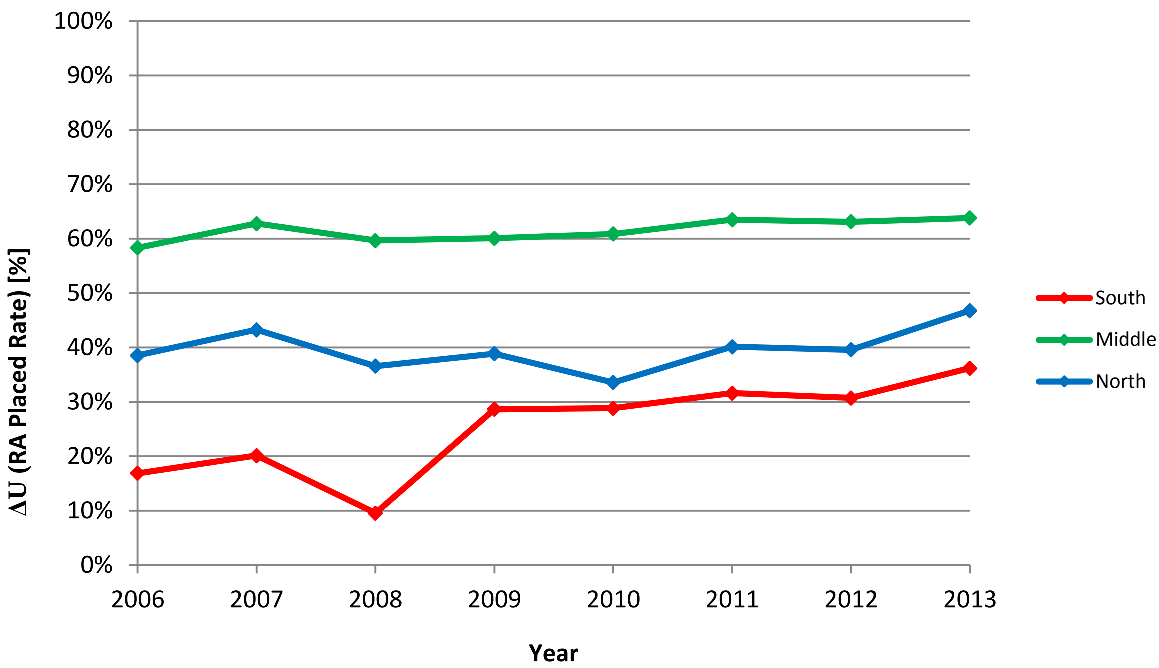

Figure 16: RA Placed Rates for: south Europe (red country); middle Europe (green country); north Europe (blue country)

The "RA Placed Rates" calculated show a trend affecting substantially constant referring to the Middle European area (an average value equal to about 60%); the North area trend is also approximately constant and equal to about 40%; finally, the Southern Europe trend is slightly growing and its average value is about 25% (Figure 15 and Figure 16).

In order to analyse more in depth these data, two more parameters have been defined, respectively "RA available Quantity Factor" QF(a) and "RA placed Quantity Factor" QF(p):

$$QF(a) = \frac{RA\ Available}{RA\ Available + H\&WMA} \times 100$$

$$QF(p) = \frac{RA\ Placed}{RA\ Available + H\&WMA} \times 100$$

QF(a) and QF(p) respectively represent the incidence of the RA available compared to the total asphalt production (sum of recycled asphalt and virgin asphalt) and the incidence of RA placed compared to the total asphalt production already defined. The results obtained from this calculations are shown in the following tables (Table 1, Table 2 and Table 3) and graphically summarised in Figure 17.

Table 1: Significant Parameters for South Europe Area

SOUTH EUROPE						
YEAR	**H&WMA**	**RA Available**	**RA Placed**	**ΔU**	**QF(available)**	**QF(placed)**
2006	166,6	21,19	3,57	17%	11%	2%
2007	173,4	22,17	4,46	20%	11%	2%
2008	171,8	21,84	2,08	10%	11%	1%
2009	161,6	21,99	6,29	29%	12%	3%
2010	155,3	22,21	6,40	29%	13%	4%
2011	154,9	22,25	7,03	32%	13%	4%
2012	130,1	20,70	6,36	31%	14%	4%
2013	133,1	18,33	6,63	36%	12%	4%

Table 2: Significant Parameters for Middle Europe Area

MIDDLE EUROPE						
YEAR	**H&WMA**	**RA Available**	**RA Placed**	**ΔU**	**QF(available)**	**QF(placed)**
2006	151,2	27,12	15,81	58%	15%	9%
2007	142,6	26,17	16,42	63%	16%	10%
2008	138	27,18	16,21	60%	16%	10%
2009	139,4	28,12	16,88	60%	17%	10%
2010	128,6	27,58	16,79	61%	18%	11%
2011	141,85	28,27	17,94	63%	17%	11%
2012	121,01	25,83	16,29	63%	18%	11%
2013	118,6	26,16	16,69	64%	18%	12%

Table 3: Significant Parameters for North Europe Area

NORTH EUROPE						
YEAR	**H&WMA**	**RA Available**	**RA Placed**	**ΔU**	**QF(available)**	**QF(placed)**
2006	23,7	1,48	0,57	39%	6%	2%
2007	26,9	1,99	0,86	43%	7%	3%
2008	28,2	2,66	0,97	37%	9%	3%
2009	26,1	2,60	1,01	39%	9%	4%
2010	25,4	3,22	1,07	34%	11%	4%
2011	27,5	3,44	1,38	40%	11%	4%
2012	25,3	3,38	1,34	40%	12%	5%
2013	25,5	3,25	1,52	47%	11%	5%

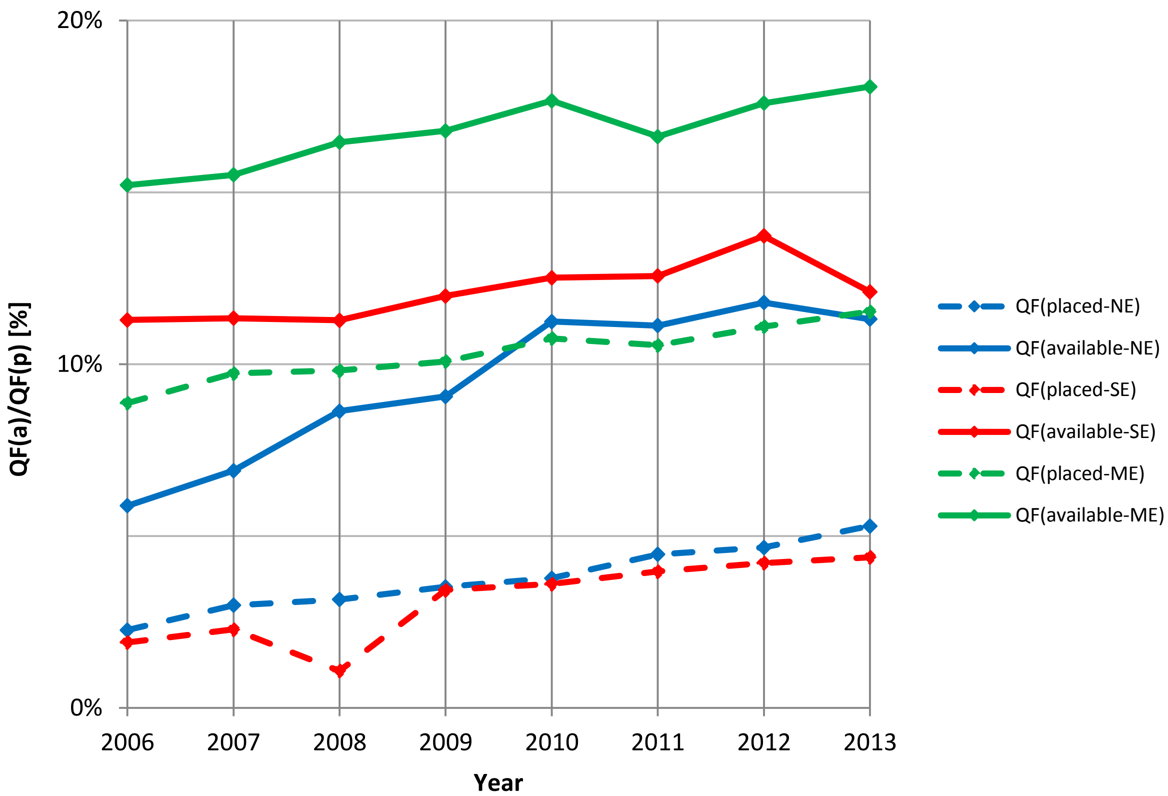

Figure 17: RA Quantity Factors for: south Europe (red country); middle Europe (green country); north Europe (blue country)

Thus, the available RA is slightly increasing over the time. It is worth of being highlighted that, QF(p) referring to the placed RA, all quantity factors are growing.

Finally, these information can be summarised:

- production of H&WMA in Europe is substantially decreasing within each area and therefore globally;
- RA production in Europe shows a marked growth until 2011 and after it there is a significant decrease;
- RA reused within flexible pavements shows a fluctuating tendency still growing.

So, according to the aim of the research already declared, firstly and mainly sustainability and therefore respecting technical-economic bonds, expected results are:

- Decrease of H&WMA production (saving non-renewable resources);
- Increase RA production;
- Increase RA reused in new flexible pavements.

Finally, but also very important, is the improvement of Warm Mix Technologies for producing bituminous mixtures in order to save energy and to reduce fuel consumption, in other words - obtaining a significant reduction of pollutant emissions.

2 Scope and Objectives

The scope of the report is to define the guidelines of drafting of an RA End-Users Manual addressed to all stakeholders such as road agencies, production plants and construction enterprises.

Therefore it is necessary to analyse the whole RA process coming from the dismantling of old pavements to the placing of asphalt mixes incorporating RA within new pavements (Figure 18).

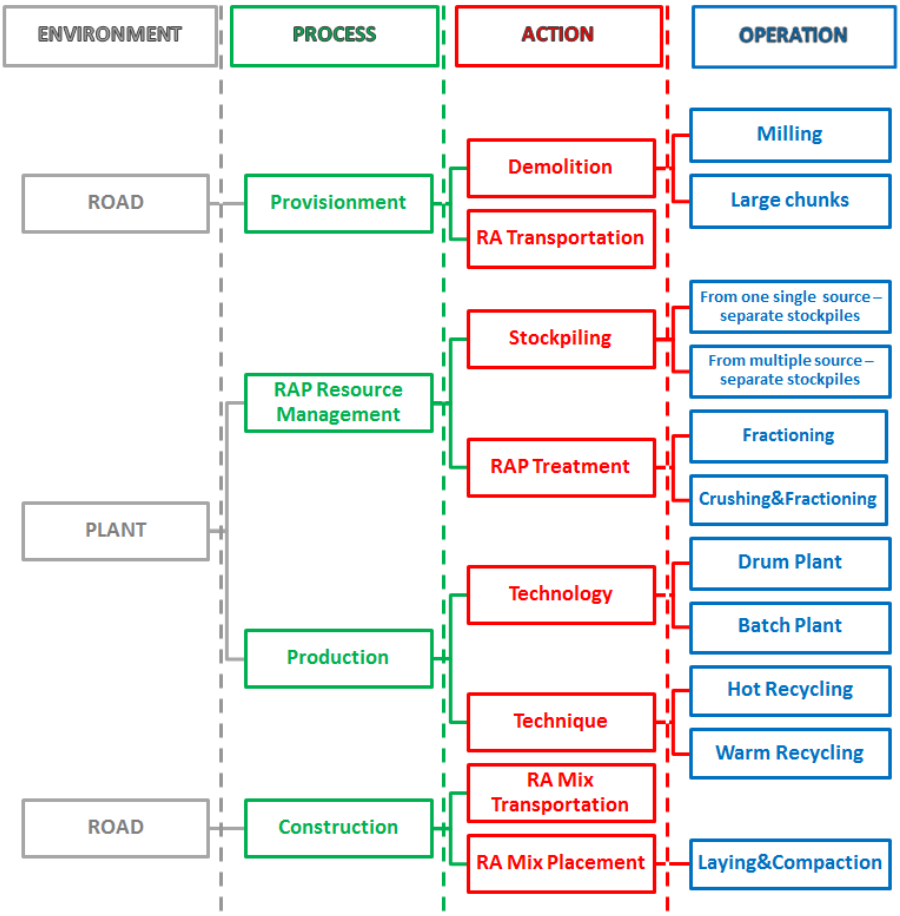

Figure 18: Framework of the whole RA process

Before proceeding to any definition of guidelines, it is necessary to establish what the objectives are that have to be achieved through them. In the light of multi-year use of Reclaimed Asphalt, most of all in most cases where high RA contents where used the sometimes intrinsic heterogeneity of RA can lead to effect that the mixture coming from the plant is different to the designed one. Certainly, this could reflect also on the performance of the pavement.

Ultimately, two main technical goals can be clearly summarised: (i) the consensus between mixtures produced in laboratory or in plant; (ii) the achievement of the pavement performances provided by the mix design.

Therefore the main concept behind the idea of the End-Users Manual lies on trying both to maximise the RA use within new road pavement and to improve the performance of the super-structure.

In order to approach the issues in a systematic way firstly separate analysis of the various phases identified above were carried out through academic and scientific publications as well as technical reports. At a later stage, a method of preparation of the End-Users Manual, based on specific check-lists for each user; was tuned. Finally an application to the real German and Italian case studies was performed.

3 Analysis of the Provisionment

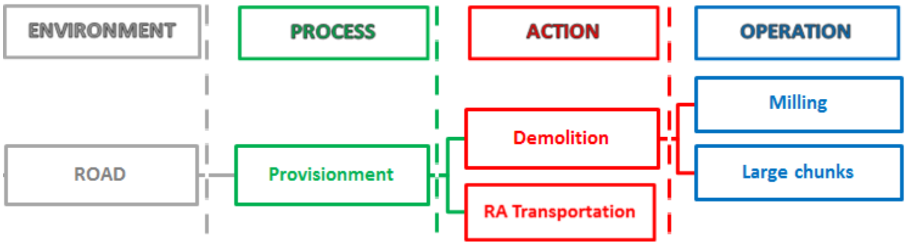

Figure 19: Partial Framework-Provisionment

3.1 Pavement Demolition

Existing pavements can be demolished by block crushing or milling. For block crushing the entire bound pavement structure is demolished, whereas the depth of milling can be varied between some millimetres and some 10 centimetres depending on the milling equipment.

Some recycling techniques are less dependent on the characteristics of the reclaimed road material than others. For high quality asphalt mixes (usually hot-in-plant) the requirements on composition demands homogeneous reclaimed materials, in which grading and binder content as well as aggregate and binder properties meet the requirement for virgin materials. In hot in plant recycling, for example, the binder of reclaimed materials is melted during mixing process and therefore reactivated. This may require separate milling of single layers, which is of importance especially if RA shall be reused in surface asphalt mixes (Direct-MAT, 2013-a).

Other recycling techniques only need homogeny conditions whereas the actual composition of the reclaimed material in detail (e.g. grading of aggregates, binder content, and binder properties) can be neglected. In cold recycling technology the grading of the reclaimed material is of importance but its actual composition of reclaimed asphalt, cement bound layers or unbound material is of less importance.

Mix control procedure and results, explanation for differences between designed materials and materials produced in plant.

3.1.1 Milling

Generally, the milling as demolition technique has the following advantages:

- Flexible milling depth depending on milling equipment;
- Milling results in grain size of reclaimed road material which usually allows the application in new asphalt mixes without further processing (crushing and/or sieving) which is the precondition of in-situ-recycling techniques;
- Milling layer by layer allows the reclamation of single-source materials with high homogeneity allowing the reuse in asphalt mixes with high recycling rates;
- Separating milling allows the removal of road material for recycling which is paved on top of layers containing hazardous substances (e.g. tar). Therefore, the contamination of clean material is avoided;
- Prior removal of thick road marking materials by thin layer milling to improve RA Quality.

The actual milling operation depends on milling equipment, milling speed, size of milling drum and cutters. The size of reclaimed material also depends on the pavement characteristics as cracked layers and missing interlayer bonding will affect the grain size. For cold milling operations the temperature of the reclaimed layer affects the milling operation (Direct-MAT, 2013-a).

Milling is a beneficial part of pavement rehabilitation. Advantages of milling include the following:

- Removes distressed pavement layers;
- Maintains clearances under bridges and avoids build-up of pavement weight on bridge;
- Avoids filling up curbs and avoids drop-offs at drainage inlets in urban settings;
- Reduces the need for the costly addition of shoulder material along the edge of pavements on rural roadways;
- Restores pavement grades and profiles, which are important for smoothness;
- Leaves a rough texture on the remaining surface that creates a very good bond with an overlay;
- Is an efficient removal process that can be done within a short lane-closure with the paving operations?

Selection of the milling depth is a critical agency decision in planning the rehabilitation of a pavement. Often, a milling depth is based on visual examination of cores to determine the depth of surface cracks and/or the location of weak layers or interfaces. Removal of these distressed or weak layers helps achieve long-term performance of the overlay. Cores should be taken at least once every lane mile on highways and one per lane per block on city streets. It is important to check the cross-section of pavement layers across lanes, since roads have often been widened in the past with a different build-up on the added roadway width.

Milling processes should be closely examined to make sure the milled material is not contaminated with soil, base material, paving geotextiles, or other debris. This is particularly important for deep mills or milling on shoulders or widened roadways. Milled materials that become contaminated should be used only as shoulder material and should be stockpiled separately from RA to be used in asphalt mix. A recommended maximum limit of 1 percent deleterious material should be used to evaluate RA contamination. This limit is consistent with requirements for virgin aggregates (NCRHP, 2013).

3.1.2 Large Chunks

RA may also be obtained from complete demolition of an existing pavement using a bulldozer or backhoe. This process is typically limited to small areas of pavement. It is slow and results in large chunks of pavement that may be more challenging to process into a useable recycled material. When pavement rubble is contaminated with underlying layers and soil, it is better for this material to be crushed and used as a shoulder or base material than used in an asphalt mixture (NCRHP, 2013).

The crushing of blocks may be feasible for smaller work sites as well as sites where the road structure is demolished in full depth (Direct-MAT, 2013-a).

3.1.3 RA Transportation

The transportation of RA must be made according to the procedure for transport of non-hazardous waste, being careful to waterproof the material with suitable tarpaulins.

4 Analysis of the RA Resource Management and Production Process

4.1 Resource Management Production (RAP)

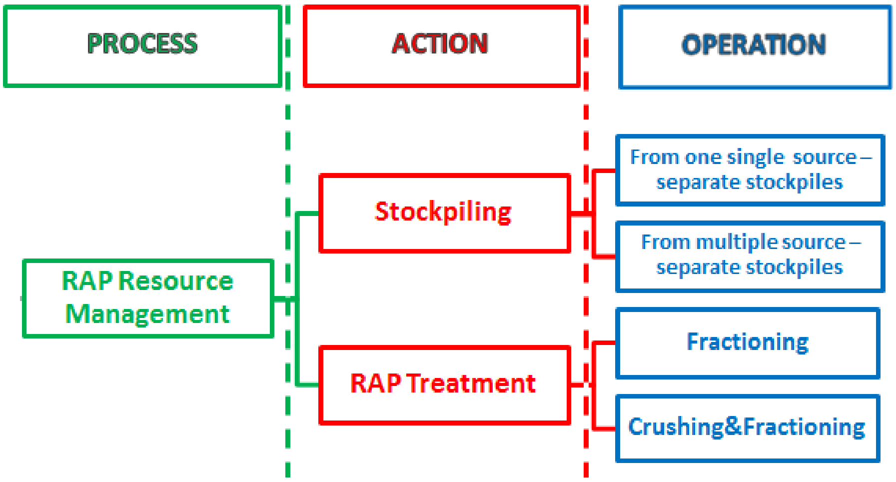

Figure 20: Partial Framework-RA Resource Management

4.1.1 Stockpiling

RA stockpiles should be treated just like any virgin aggregate stockpile to avoid contamination and to guarantee separation of different materials. The start-up waste should not be mixed together with RA material. If RA from different sources is stored in the same stockpile it can be blended to increase homogeneity before processing or feeding in to the cold feeder. Moisture content in RA is an important factor that can limit the maximum RA content. It will cause higher drying and heating costs, reduce the plant production rate, and increase emissions by 10% for every 1% moisture increase. Moisture content can be reduced by the following actions, in the order of most to least effective (Zaumanis M. et al., 2014):

- Covered stockpiles under a roof;
- Use of paved, sloped storage area;
- Use of tall conical stockpiles;
- Crushing and screening of RA in small portions at the day of use.

RA has a tendency to hold water and bad to drain over time, like virgin aggregate stockpiles, and therefore the moisture content in RA stockpiles in general is higher compared with aggregate stockpiles. Low, flat, horizontal stockpiles can have up to 8% moisture. Increased moisture content will cause higher drying and heating costs, reduce the plant production rate and, in many cases, it may even limit the amount of RA in mixture. For example, when running RA through a parallel flow drum or batch plant, the steam from the drying process will strip the light oil from asphalt, which can oil-soak the baghouse, and lead to visible emissions.

A study by West has shown that the gradation of multiple source RA stockpiles can be even more consistent than that of virgin aggregates. RA may tend to pack together in a hot climate and long storage times. This can be avoided by processing RA shortly before mixing or by blending with sand (Zaumanis M. & Mallick R. B., 2015).

The storage of RA on separated stockpiles according to its properties is recommended but requires large storage area near the mixing plant. The storage of RA on separated stockpiles will improve the homogeneity of the stockpiled RA and will enable higher recycling rates in the final mixes. The stockpiles can be separated according to following RA properties:

- Maximum grain size;
- Type of RA asphalt type (grading):
  - Because the grading of RA compared to the grading of the final mix strongly influences the possible recycling rate, separated stockpiles for different types of asphalts (e.g. SMA, AC, MA) is recommended;
- Type of binder (e. g. modified binder, binder viscosity).

The separated storage of RA originating from one single source road can be feasible to reach a high homogeneity of the RA that will increase the possible recycling rate.

Because the water content of RA may reduce the possible RA content, roofed stockpiles are recommended for RA applied in HMA.

For stockpiles, which contain RA from several sources a regular stockpile, homogenization might be feasible in order to insure the actual quality of the RA material. Proper management of incoming RA and the use of homogenized stockpiles can control the composition of the RA stored in one stockpile in order to ensure constant composition and properties (Direct-MAT, 2013-a).

One of the first decisions in inventory management of RA should be whether to put all incoming RA materials into a single pile or to create separate stockpiles for RA obtained from different sources. This decision will likely depend on the following factors:

- Whether the state or primary local agency allows RA from other sources in asphalt mixes produced for its agency specifications;
- Whether the state or other primary local agency requires captive stockpiles or allows continuous replenishment of stockpiles;
- The space available at the plant site for RA processing and stockpiling;
- The target RA percentages in the asphalt mixes to be produced;
- How much RA comes from a single project?

Some agencies' specifications allow only RA from their projects to be used in their mixes. RA from agency projects are often referred to as "classified RA" since the origin of the materials is known. This limitation is used to assure that the aggregate and binder in the RA were of satisfactory quality in the original pavement. Most agencies allow the use of RA from multiple sources, including "unclassified RA" that has been combined and processed into a single uniform RA stockpile.

Agencies typically allow this practice with the stipulations that the combined blend of RA and virgin aggregates meet the appropriate SUPERPAVE consensus aggregate requirements and the volumetric properties of the recycled mix design meet all of the standard asphalt mix specifications. When this approach is used, good processing practices of the multiple-source RA material are necessary to create a uniform material. Since many contractors report that a substantial amount of their RA comes from non-DOT sources, this approach enables them to best utilize RA from different sources in a wide range of mix designs and requires the least amount of testing and mix design work. In other words, using just one RA stockpile in many different mix designs is efficient from a testing point of view. Agencies that prohibit the use of RA processed from multiple sources will suppress the use of RA. In many cases, it is not cost effective to perform all the necessary tests and mix designs for small quantities of RA.

Another requirement some agencies impose on RA stockpiles is that no additional material can be added to a RA stockpile once it is built and tested. This is referred to as a "captive" RA stockpile. A few agencies take this same approach with virgin aggregate stockpiles. The opposite and more common approach is to allow stockpiles to be continuously replenished with new material. Most agencies use this approach for virgin aggregates because there are other controls on aggregate testing at the source. This is appropriate for RA as well, if consistency can be established through a RA quality control plan. The more conservative captive stockpile approach is based on the premise that the properties of the stockpile must be precisely known if it is to be used as a component in hot mix asphalt. However, some contractors have been able to develop RA processing practices using continuously replenished stockpiles that have very consistent gradations and asphalt contents over a long period. Determining if the RA processing provides a consistent material over time requires regular testing and analysis of the RA to document the RA stockpile variability.

In some cases, limited stockpile space may constrain processing and stockpiling practices. Plant yards with limited space for stockpiles may not have sufficient room for multiple small RA stockpiles. This has been one factor that affects how some contractors use RA.

In most cases, processed RA will be moved from the location where it is screened and/or crushed to another location that is more convenient for feeding into the asphalt plant. This is another opportunity to remix the material and improve its consistency. Using the loader to dig into the RA stockpile, at the processing unit and at different locations around the pile and re-mixing loads while building the stockpile at the final location can again be used to average out variations.

As with virgin aggregates, there is a potential for RA materials to become segregated in stockpiles. This is a common problem when stockpiles are built using fixed conveyors that allow the RA particles to drop long distances to the stockpile. Larger particles have more kinetic energy and will tend to roll down toward the bottom of the stockpile. This results in more coarse particles with a lower asphalt content at the base of the stockpile and finer, higher asphalt content RA in the top of the stockpile. This problem can be minimized by using indexing-type conveyors that extend and raise the end of the conveyor as the size of the stockpile increases. If segregation is evident, a front-end loader can be used to remix the stockpile.

Moisture content of aggregates and RA is a primary factor affecting an asphalt plant's production rate and drying costs. Some contractors have implemented creative approaches to reducing moisture content in stockpiles. The best practice to minimize the accumulation of moisture in stockpiles is to cover the stockpile with a shelter or building to prevent precipitation from getting to the RA; it is a good practice to use conical stockpiles to naturally shed rain or snow, and to place the stockpile on a paved and sloped surface to help water drain from the pile. Irregular-shaped stockpiles with surface depressions that will pond water should be corrected by shaping the pile as it is being built with the frontend loader or a small dozer. However, the use of heavy equipment on the top of RA stockpiles should be minimized to avoid compaction of the RA. Likewise, it is also recommended that RA stockpiles be limited to 20 feet in height to reduce the potential for self-consolidation of the stockpile.

All asphalt plant operations generate some waste during plant start-up, transition between mixes, and clean out. Generally, start-up and shutdown plant wastes have very low asphalt contents. Another form of waste is mix rejected from a project due to incomplete coating or due to the mix temperature being too high or too low for the job. Other situations that may result in wasted mix include trucks loaded with too much mix to finish the job or mix that could not be placed due to inclement weather. These waste materials are often stockpiled for later pro-cessing into a recyclable material. Since these waste mixes have not been subjected to environmental aging from years of service, the asphalt binder is less aged than RA recovered from the road.

Waste materials also have fewer fines than other sources of RA since it was not milled or bro-ken up during demolition. However, waste materials must be thoroughly mixed and processed to make them into uniform, recyclable materials. Waste materials are often combined with other sources of RA in multiple-source stockpiles. It is important that stockpiles be kept free of contaminants from the beginning. Truck drivers bringing materials onto the plant yard must be clearly instructed where to dump their loads so that unwanted construction debris does not end up in the RA stockpile and instructed that they should clean the truck beds before hauling millings or useable RA. The plant QC personnel and the loader operator should also regularly inspect unprocessed and processed RA stockpiles to make sure they do not contain deleterious materials. If contaminants are found, dig them out immediately so that they are not covered up with other RA brought onto the yard.

A well-executed sampling and testing plan for RA is necessary to assess the consistency of the RA stockpiles and to obtain representative properties for use in mix designs (NCRHP, 2013).

4.1.2 RA Treatment

In plant RA can be further manufactured to improve its characteristics in order to enable higher recycling rates. For pre-processing of RA before adding to the final mix following works are recommended:

- Crushing;
- Sorting/sieving;
- Homogenisation.

The sorting according the RA grain size (sieving) after milling and/or crushing will improve the homogeneity of the resulting RA fraction. By sieving separated fractions, the resulting RA with smaller maximum grain size U and finer RA aggregate grading can also be added to finer asphalt mixes (e. g. surface asphalt mixtures), where the specification limits both the RA grain size as well as the RA aggregate grain size (e. g. the maximum aggregate size of the RA). Generally, the maximum RA grain size shall be the same or smaller than the maximum aggregate size of the final mix (Direct-MAT, 2013-a).

Poor management of RA stockpiles is commonly cited as one reason agencies are reluctant to increase allowable RA contents in asphalt mixtures. This section provides guidance on inventory management of RA materials and options for stockpiling, crushing, and screening RA. Good materials management practices should always be a part of the quality control program for any asphalt mix production operation. For the production of quality mixes with high RA contents, excellent materials management practices are essential.

RA management should begin with a basic inventory analysis of available RA and mix production. This analysis is important to establish realistic goals for how much RA can be used at a particular plant. The analysis includes the following four simple steps:

1. An inventory of RA on hand and RA generated per year;
2. A summary of mixes produced per year by mix types and customers;
3. Determining the maximum amount of RA that can be used;
4. A comparison of the quantity of RA available and of the amount of RA needed.

The basic goals of processing RA are to (NCRHP, 2013):

1. Create a uniform stockpile of material from a collection of different RA materials from various sources;
2. Separate or break apart large agglomerations of RA particles to a size that can be efficiently heated and broken apart during mixing with the virgin aggregates;
3. Reduce the maximum aggregate particle size in the RA so that the RA can be used in surface mixes (or other small nominal maximum aggregate size mixtures);

4. Minimize the generation of additional P200 (i.e., dust).

Vertical integration of the materials RA supply chain, including the milling, processing, storage, and quality control operations, would greatly benefit the quality of final product. The best practices of RA management are discussed below.

Asphalt pavement can be milled in partial or full depth. Road constructions where the different layers have aggregates or binder of various quality or grade should be removed by partial milling, in order to later allow the use of RA in higher value layers. Choice of the milling apparatus, depth and speed will all influence the quality of RA. Special attention should be given to minimize fines content. For example, slow forward speed or fast drum rotation will generate more undesirable fines. “SmartPave System” designers indicate that generally the RA milled with upward cut milling heads stay within 10% of original gradation. In most cases, production of 100% RA mixture will require processing of RA in order to provide several fractions. Screening of the material provides flexibility to the mix designer for ensuring the necessary particle size distribution and give control over the binder and fines content. Crushing, however, should be avoided in order to reduce generation of excessive fines content that is usually already present from milling operation. Too high fines content can significantly restrict the RA mixture design by not meeting the mixture aggregate size distribution requirements, dust to binder ratio, air voids, and VMA (Zaumanis M. et al., 2014).

Millings from a single project are usually very consistent in gradation, asphalt content, aggregate properties, and binder properties. Therefore, when a contractor obtains a large quantity of millings from a single project, it is considered a best practice not to further crush this material, but rather to use it “as-is” in mix designs or to screen the millings to remove large particles.

Recommended processing options:

1. Receive millings from project;
2. Sample and test a few locations of the millings stockpile to determine the as-received gradation and check the maximum aggregate size;
3. If the maximum aggregate size of the as-received millings is small enough to use in the desired mix design(s), do not further process the millings;
4. If maximum particle size is too large for desired mix(es), then either
   a. Fractionate the RA over a screen equal to or smaller than the NMAS of desired mix(es). Stockpile the fine RA (portion passing through the screen) and test for properties. Stockpile the coarse RA fraction(s) into separate stockpile(s) for use in other, larger NMAS mixes, or
   b. Crush the millings so that they will pass the desired screen size. This is the least desirable option because it will result in more uncoated faces of RA particles and generate additional dust, which can severely hamper how much of the crushed RA can be used in mix designs. When a contractor wants to increase RA contents but is often limited by VMA requirements or the dust-to-binder ratio during mix designs.

RA materials from multiple sources that have different compositions must be processed to create a uniform material suitable for use in a new asphalt mixture. Around the world, contractors have found that they can make a uniform and high-quality RA from a combination of pavement rubble, millings, and wasted mix. The key to achieving a consistent RA from multiple sources is careful blending as part of the processing operations. A bulldozer, excavator, or similar equipment should be used to blend materials from different locations in the multiple-source RA stockpile as it is fed into the screening and crushing operation (NCRHP, 2013).

4.1.2.1 Crushing

RA originating from block-crushed pavements needs to be further crushed in the mixing plant. But also large lumps of RA coming from milled surfaces may be crushed in order to reach smaller grain sizes of RA.

Smaller grain sizes will decrease the necessary mixing time as RA conglomerates don't need to be disintegrated in the mixer.

For crushing, mainly mobile crushing units are used. They can be operated both near the demolition site prior to RA transport to mixing plant as well as in several mixing plants.

Additional crushing might be necessary for RA which was stockpiled for long storage time as the RA grains conglomerate especially at high storage temperatures and sun exposure (Direct-MAT, 2013-a).

Since crushing RA will create more aggregate fines, it is best to set up the crushing operation so that the RA is screened before it enters the crusher. This will allow the finer RA particles that pass through the screen to bypass the crusher.

Some RA crushing units are set up so that all of the RA is conveyed from the feeder bin into the crusher, followed by a recirculation circuit after the crusher. The recirculation circuit is designed to return larger particles that do not pass through the screen back to the crusher. However, since all of the material must go through the crusher in the first pass, there is a good chance that breakdown will occur for some smaller particles that did not need to be reduced in size.

Moisture and temperature can affect crushing and screening of RA. When the RA is wet and/or temperatures are hot, RA will be stickier and tend to build up in feeders and crushers, blind screens, and RA fines will stick to belts and accumulate under conveyors. Not only does this require more maintenance of RA processing units and RA feeder systems for mix production, it can also affect the gradation and asphalt content of the RA.

A variety of crusher types are used for crushing RA. Many contractors have found that the best type of RA crushers are horizontal-shaft impactors (HSIs) and roller or mill-type breakers made specifically for processing RA. These RA crushers/breakers are designed to break up chunks of pavement or agglomerations of RA rather than downsize the aggregate gradation.

Compression-type crushers such as jaw crushers and cone crushers tend to clog due to packing (caking) of RA when the RA is warm or wet.

Some contractors have used milling machines to crush stockpiled RA. There may be a risk of the milling machine overturning since the stockpile is uneven and may not provide stable support for the heavy machine. No data are available regarding the effectiveness of this method of processing in terms of size reduction or consistency of the RA.

RA crushers or crushing circuits that are built into the asphalt plant's RA feed line can change the gradation of the RA material being fed into the mix. Gradation test results on the stockpiled RA then become meaningless, and the quality control technician will have to make unnecessary, and probably substantial, mix adjustments to get the mix gradation and volumetric properties in specification during production start-up. In many cases, this could result in the technician reducing the RA content in order to meet the quality control tolerances for the mix.

In-line roller crushers (also known as lump breakers) and reduced-speed impact crushers designed to break up agglomerations of RA rather than change the gradation are used by some contractors. It is recommended to conduct a simple extracted gradation check of RA samples before and after the in-line crusher to determine if it is breaking down the RA aggregate (NCRHP, 2013).

4.1.2.2 Fractioning

Fractionating is a process gaining popularity in which RA is screened into two or three sizes. In some cases, the material is returned to a crusher, and the crushed material is then returned to the screening unit. The primary advantage of fractionating RA is that having stockpiles of different RA sizes provides more flexibility in meeting mix design requirements.

Producers that can answer "yes" to the following six questions should consider fractionating RA:

1. Can your plant produce mixes containing 20 percent or more RA without emission problems or significant decline in production rate?
2. Does the market this plant supplies allow RA contents above 20 percent (probably should be specific with a quantity of mix per year)?
3. Does your plant have an excess amount of RA (i.e., the quantity of RA stockpiled exceeds RA usage per year)?
4. Does your plant site have at least 10,000 sq. ft. available in the stockpile area for a RA fractionation plant?
5. Do you have difficulty meeting mix design requirements such as minimum VMA, dust proportion, or P0.075 content for mixes with over 20 percent RA?
6. Do you have trouble keeping RA mixes within quality control and acceptance limits?

The decision of whether to fractionate RA into different sizes should be the mix producer's choice and not a specification. Some agencies have recently begun to require RA fractionation for higher RA contents. This type of method specification is not appropriate; a better approach to assure consistency of RA is to set limits on the variability of the RA stockpiles (NCRHP, 2013).

4.2 Production Process

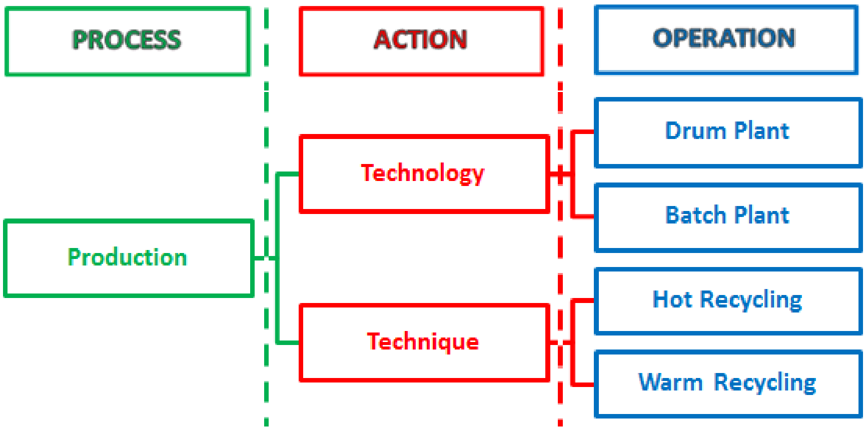

Figure 21: Partial Framework-RA Mix Production

Generally, two techniques can be applied on asphalt pavements:

- in-situ recycling, where the old pavement material remains on site, after being processed using mobile equipment;
- plant recycling, where the dismantled road material is transported to mixing plants.

With both recycling techniques, the reuse of reclaimed asphalt in situ or in plant can be divided into (Direct-MAT, 2013-b):

- hot recycling, where RA is mixed with new aggregates and hot bitumen, laid and compacted as normal hot mix asphalt at temperatures around 150°C (HMA);
- warm recycling, where RA is mixed with new aggregates and hot bitumen with the addition of additives or foamed bitumen, which enable the reduction of the mixing, laying and compaction temperature (>100°C);
- cold recycling, where RA is mixed with new aggregates and bitumen emulsion or foamed bitumen with the possible further addition of hydraulic binder if required (~20°C, environmental temperature).

Here only the production of reclaimed asphalt in plant has been analysed.

4.2.1 Technology

4.2.1.1 Drum Plant

In a conventional drum plant (Figure 22), a centre entry is used to introduce RA to the superheated virgin aggregates. The hot virgin aggregates are required to dry, heat and mechanically mix with the RA. The RA is protected from the burner flame by a veil of aggregate in a parallel flow drum or is introduced behind the flame in counter-flow drum, but there are multiple modifications to these systems. To ensure maximum blending, it is recommended to use early entry RA collars and long mixing chambers. The main limiting factors for increasing RA content:

- moisture content and ambient temperature of the materials;
- production rate;
- discharge temperature;
- allowable moisture content in the final mix;

- build-up of fine aggregates and asphalt binder on metal flights in drum.

Most conventional drum plants can routinely accommodate 50% RA. The maximum amount of RA that was found reported in conventional drum plant is about 70%, although Kandhal and Mallick notes that problems with ‘blue smoke’ can occur from volatilisation of RA binder. Various proprietary heating drums (e.g. double drum) and/or production systems have been developed recently that allow to increase the RA amount without the need to excessively superheat the virgin aggregates or expose RA to direct flame (Zaumanis M. & Mallick R. B., 2015).

The Reclaimed Asphalt Pavement (RA) material cannot be processed in normal drum mix plants since excessive “blue smoke” is produced when the RA comes in contact with the burner flame. The condition is further aggravated by build-up of fine aggregates and asphalt binder on metal flights and end plates. It has been suggested that most of the smoke problem is caused by the light oils in soft grade of asphalt binder used to rejuvenate the aged asphalt in the RA. Although the smoke problem could be solved by various processes such as lowering HMA plant’s production rate, increasing water content of the RA, lowering discharge temperature of the recycled mix, introducing additional combustion air and decreasing percentage of RA, it was found that a more effective way to rectify the problem was to modify the drum mix plant.

The RA is introduced into the drum downstream of the burner flame to mix with the superheated new aggregates. The hot virgin aggregates heat up the RA material by conduction. The RA is protected from coming in direct contact with the burner flame by a dense veil of aggregate added prior to the point where the RA is added. It is very important to have the veil of virgin aggregate. Otherwise, overheating of RA can result in “blue smoke,” and it may not be possible to use the design amount of RA material. Sometimes special flight design, steel ring dams, or circular steel flame shields are utilized to force the RA to mix with the virgin aggregates be-fore being subjected to the high gas treatment. These techniques eliminate “blue-smoke” problem.

Another type of the plant the parallel flow drum mixers were effectively used for recycling in the ‘70s and ‘80s. However, the plants had difficulty in complying with the growing number of restrictive emission standards. In some cases, the problem was caused by the production of steam that distilled light oil from the virgin asphalt binders and RA. The important factors contributing to the problem of emission are high moisture content of the aggregates, higher amount of fines in the RA material and a relatively long time of exposure of the asphalt binder to the steam in the gas stream. Several modified versions of the drum mix plant have been built to counter the emission problem. In general, in these methods the exposing of the asphalt binder to the steam in the exhaust gas stream has been eliminated, and this has eliminated the emission of light ends to the baghouse, except the minute amounts of light oil emitted from recycled material when a high percentage of RA is used.

In a parallel-flow drum mixer with an isolated mixing area, the mixing device is welded to the dryer shell so that it rotates with the dryer. The gas stream is removed from the dryer prior to the aggregate/RA mixture entering the mixing area. Some designs vent to the mixing area back to the combustion area of the dryer. This equipment requires a primary collector for capture of the larger dust particles. The particles collected are typically returned to the mixing area of the dryer with a screw conveyor.

In a parallel-flow drum mixer with counterflow RA drying tube, the RA is introduced into a cooler portion of the dryer and travels against the gas stream to mix with the virgin aggregates in the area where the aggregate/RA mixture enters the mixing area of the dryer. In this type of drum hydrocarbon levels are greatly reduced from the gas stream because the new liquid asphalt is shielded from direct exposure to the gas stream, and the aggregate is superheated for some conductive heat transfer to the RA while the convective heat transfer of the RA occurs in a cooler portion of the dryer.

In another type of parallel-flow dryer drum, the RA is introduced in a separate continuous mixing device. RA is heated conductively in the mixing device. In this type of drum, RA percentages are affected by the physical space available for conductive heat transfer in the mixing device. The superheated virgin aggregates must heat the RA, and time and space are required for the moisture to be released from the RA. To avoid the occurrence of hydrocarbons in steam, the vapour and steam are directed back into the combustion area of the aggregate dryer which effectively burns any hydrocarbon left in that separate gas stream. However, the virgin aggregate are superheated in a parallel flow configuration, and the exhaust gas temperature is not lower than the aggregate temperature. Hence, the percentage of RA that can be achieved with this approach can be limited by air pollution control equipment on the facility.

The excessively high gas temperature can be avoided by changing the dryer configuration to a counter-flow dryer design (aggregate travels against gas flow).

A heat exchange chamber can be added to the aggregate dryer to heat the RA with virgin aggregates in the combustion area of the dryer. Higher RA percentages are possible because RA has a longer residence time with the superheated virgin aggregates, and because RA is heated conductively with aggregate in the vicinity of the hottest part of the dryer shell.

In a counter-flow drum mixer, a mixture dryer and a continuous mixing drum is combined in one unit. In this type of drum mixer, the virgin aggregate is heated convectively, the RA is heated conductively, and the virgin asphalt binder, recycled fines from primary and secondary collector, and other additives are added in the mixing section that is attached and rotating with the shell.

In a unitized counter-flow dryer and continuous mixer, a counter-flow aggregate dryer is combined with a continuous pug-mill mixing device. The aggregate passes through the inside of the counter-flow dryer, and then is discharged with a fixed outer mixing shell where the mixing paddles move the virgin aggregate “uphill” through a mixing bed from between the rotating drying shell and the fixed rotor mixing shell. RA is introduced at this point, along with virgin asphalt binder, recycled fines and additives, to produce HMA.

Since the late 80s two new drum designs for more efficient heat transfer to RA material during mixing have been developed. These are double barrel and triple drum design. The double barrel counterflow drum mix plant has more mixing space than a conventional drum mixer. The shell of the drum is used as the shaft of the coater. A 3 to 3.3-m (10 to 11-ft) diameter coater is created with an extremely large insulated mixing area. The virgin aggregate material is dried in the inner drum and superheated to 315°C – 343°C (600°- 650°F) (when running 50 percent RA). It then drops through the wall of the drum and meets with the RA in the annular space. Approximately 1½ minutes of mixing time occurs in this outer shell. Since the outer shell does not rotate, easy access is available to add various other recycle components to the process as they become necessary and available. The heat of the inside barrel is transferred through the rotating shell to mixing in the annular space. The outer shell of the double barrel remains at approximately 49°C (120°F) at all times, leading to a very efficient plant. In this method the virgin and the RA material are not exposed to the hot gases or to the steam of the drying process and thus the light oils are not removed from the mix. In the outer section of the double barrel, due to the moisture removed from the RA, a steam or inert atmosphere occurs resulting in a much lower oxidation or short-term aging of the recycled HMA mix in the mixing chamber. Another benefit derived from this type of plant is the much longer life occurring with the bags in the baghouse due to relatively lower temperature of the exhaust gases. As dust is discharged from the baghouse through a rotary airlock on the double barrel plant a screw conveyor is used to transfer the mix back into the outer shell. The holes through which the virgin aggregates are directed into the outer shell are also responsible for channelizing any smoke from the inner mixing section to the outer space. The pollutants go directly to the flame where they are burnt. This results in reduced emission and blue smoke. The counterflow dryer design also leads to higher production rates with much lower fuel consumption.

The triple drum design also uses an outer shell, however, a stainless steel cylinder is used to enclose the combustion chamber. This cylinder (without any flight or steps of a regular drum) is believed to be effective in transferring heat to the RA material through conduction and radiation. The virgin aggregate is introduced from the opposite end of the burner flame. The RA material is introduced in the annular space formed by the outer shell. The superheated virgin aggregates fall into the annular space and mingle with the RA material (FHWA-SA-98-042, 1997).

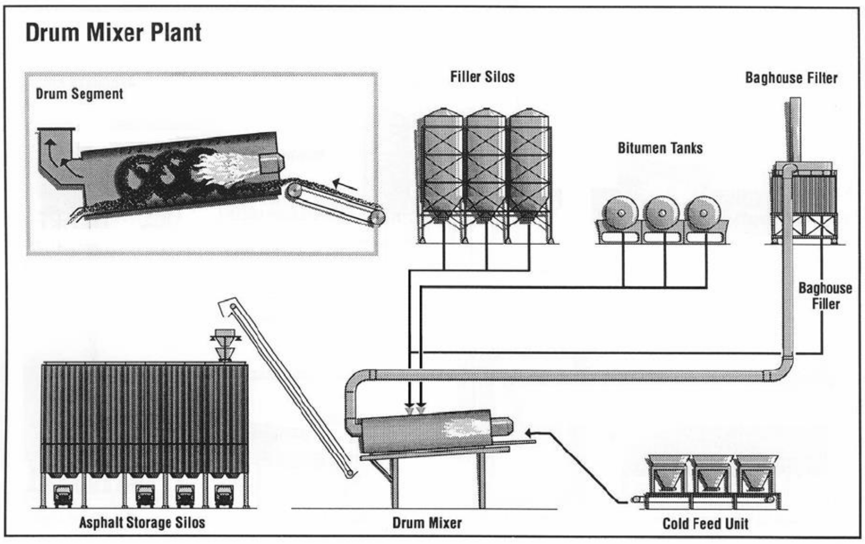

Figure 22: Drum Mixer Plant (EAPA, 2007)

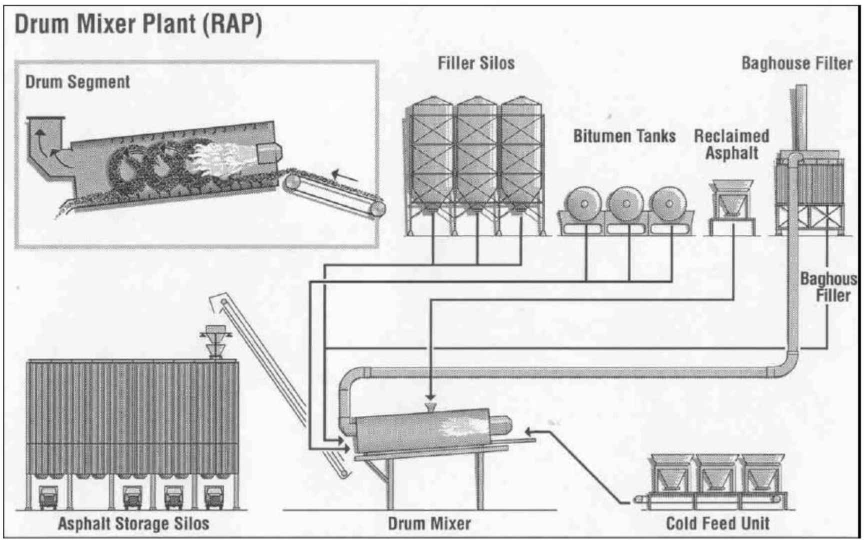

Figure 23: Drum Mixer Plant for RA (EAPA, 2007)

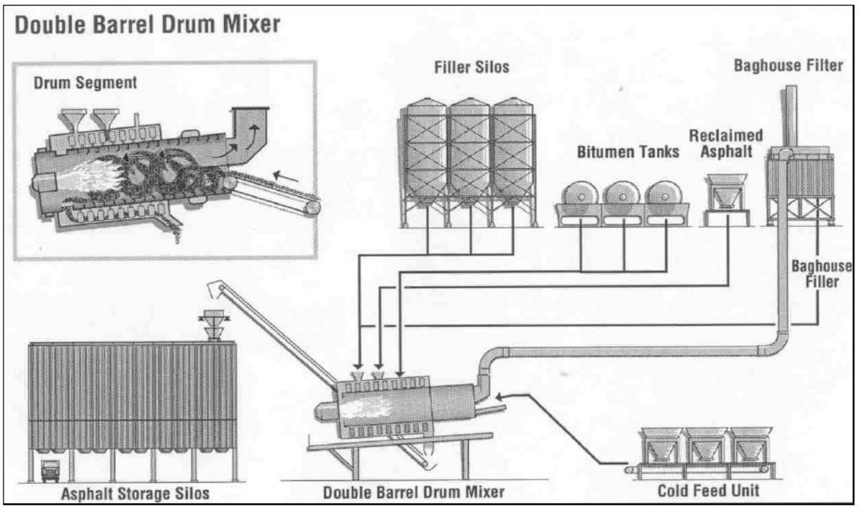

Figure 24: Double Barrel Drum Mixer Plant (EAPA, 2007)

4.2.1.2 Batch Plant

There are several methods of RA addition in batch plant:

- addition of RA before hot elevator and screening of the mixture;
- addition of RA before hot elevator without screening of the mixture;
- introduction of cold RA into weight hopper or pug mill;
- use of separate drier for heating RA before mixing with the virgin materials.

Batch plants generally do not allow as high RA use as drum plants. The typical range of RA is 10–20% and very rarely RA content exceeds 40%, although as high as 50% RA has been used.

The major technological limitations of high RA addition to batch plant include the following:

- The same factors as previously described for drum plant;
- Steam generates as soon as RA touches the hot aggregates and thermal explosion occurs when binder is added. This generates emissions and scavenge systems are usually unable to pull the steam surge from pug mill;
- Clogging of screens and hot elevator if RA is added before elevator.

To attain RA content above 40%, heating of RA is necessary. The use of a double dryer or a parallel drum for separate heating of RA allows doing it without exposing it to direct flame. In Belgium 50% RA mixtures are routinely produced using a separate large volume drum with a special burner to heat the RA to temperature between 110 and 160°C. The asphalt is then stored in an insulated silo until weighed and mixed with virgin aggregates (Zaumanis M. & Mallick R. B., 2015).

Today in Europe most asphalt plants are of the batch type. A common variation of batch type plant is the tower plant, as shown in Figure 25 (EAPA, 2007).

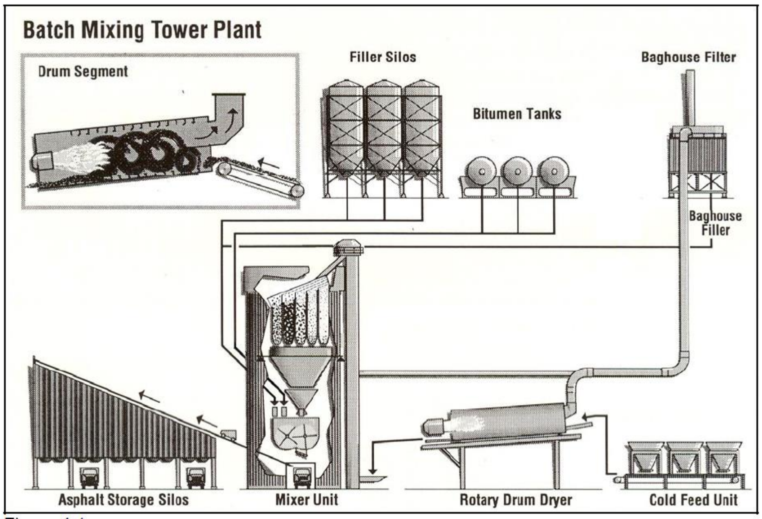

Figure 25: Batch Mixing Tower Plant (EAPA, 2007)

Raw aggregate used for the production of asphalt is normally stockpiled near or at the actual plant site. It is advantageous for energy economy to store the raw material at a location where bulk moisture content can be kept at a minimum.

From the storage piles the aggregate is hauled and placed in the appropriate cold feed hoppers. Here the different sizes of aggregate are metered on to a conveyer belt in specific portions, depending on the type of asphalt mixture required, and transported to the intake of the rotary drum dryer. The rotary dryer is a steel cylinder with flights placed on the inside. As the drum rotates, the flights lift the material and let it fall down through the hot air stream in the drum. At the same time the aggregates slowly flow forward because the drum is placed with a slight inclination. Usually the counter flow process is followed (i.e. where the gas flow direction is opposite to the material flow).

Important control parameters for the drum are angle of inclination, rotational velocity, and flight design. For the heating and drying of aggregates a gas-, coal- or oil-fired burner is placed at one end of the drum. Heat is thus mainly transferred by convection.

As part of the abatement technique, water vapour and exhaust air are sucked out at the cold end of the drum from where it is led through a dust separator. The cleaned air is finally exhausted to the atmosphere through a smoke stack. Most often baghouses are used for dust separation.

The dust collected in baghouses (filler) is continuously- or batch-fed back to the mixing process or goes to a separate silo.

After leaving the dryer the hot aggregates (temperature 135-180°C) drop into a bucket elevator and are conveyed to the top of the mixing tower. In tower plant type (hot-stock principle) the drying process constitutes a separate part of the overall process and can to some extent be carried out independently of the mixing of asphalt (Figure 25). Instead of entering the pug mill immediately after heating and drying, the aggregates are transferred onto vibrating screens and separated into different grades in individual hot aggregate storage bins. Alternatively these may be stored in a by-pass bin for direct coating. When a recipe is chosen the aggregates are promptly dropped into the weigh hopper. From the weigh hopper the aggregate goes into a pug mill (mixer) where it is coated with bitumen which is pumped from a heated storage tank, weighed and injected into the mixer. At this stage also the specified amount of filler is added to the mix. Mixing time varies between 25 and 90 seconds, depending on plant and mix type. Hot stock principle enables a rapid supply of different asphalt mixtures.

The finished asphalt mix is then transferred either directly to a waiting truck for immediate delivery to the job site or by a conveyer to heated asphalt storage silos.

One type of batch plant, although rarely used, is a screen drum plant. In this plant type the drum operates as a counter flow drum dryer. At the end of the drum the heated aggregates fall onto a screen which surrounds the dryer drum. The screen separates aggregates in to 4 or 5 different grades which are stored in hot bins. From this stage the plant operates like a normal batch mixing plant.]

The general configuration of an asphalt plant using the batch principle is described above, but the increasing use of RA sets additional requirements for the plant. The most common plant variations for recycling are introduced in the following text.

The recycling techniques include cold, hot and recycling ring methods. For all methods the broken up material must be of the correct size and may need to be screened into correct sizes before further processing.

Cold methods refer to the addition of the RA either at the discharge of the dryer into the hot elevator where the material is heated by virgin aggregates before entering the pug mill (Figure 26) or directly into the pug mill. Here the appropriate amount of new bitumen is added to the mixture according to the required properties. It is important to pay attention to avoid heating added raw materials too much. Cold methods employ recycling percentages of 10- 30%, depending on moisture content of the recycled materials, the quality of the reclaimed asphalt in relation to the required specification of the new hot mix and the technical process limitations regarding maximum permitted temperatures (EAPA, 2007).

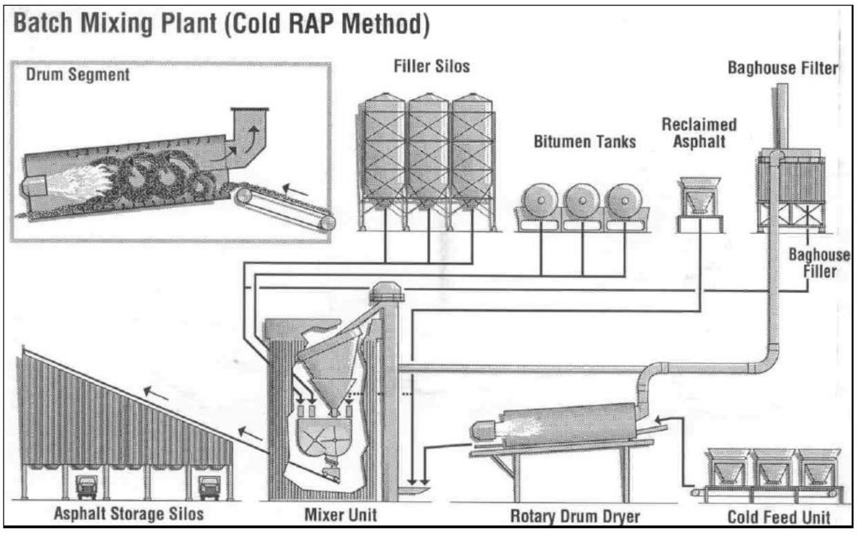

Figure 26: Batch Mixing Plant - Cold RAP Method (EAPA, 2007)

Employing the hot method means that the reclaimed material is directly preheated (Figure 27). This is usually done by using an extra dryer (tandem drum). The reclaimed material is metered and heated and dried in the second drum and transferred via a buffer silo to the mixer.

Virgin aggregates are heated in the first drum and conveyed to the mixer by following the steps described in the previous section. The hot gases from the recycling drum are led either directly to the virgin aggregate dryer drum as secondary air near the burner or to the baghouse filter. Recycling percentages for the hot method are typically 30-70%. The upper limit is determined by the quality requirements of the mix specification in relation to the properties of the RA (EAPA, 2007).

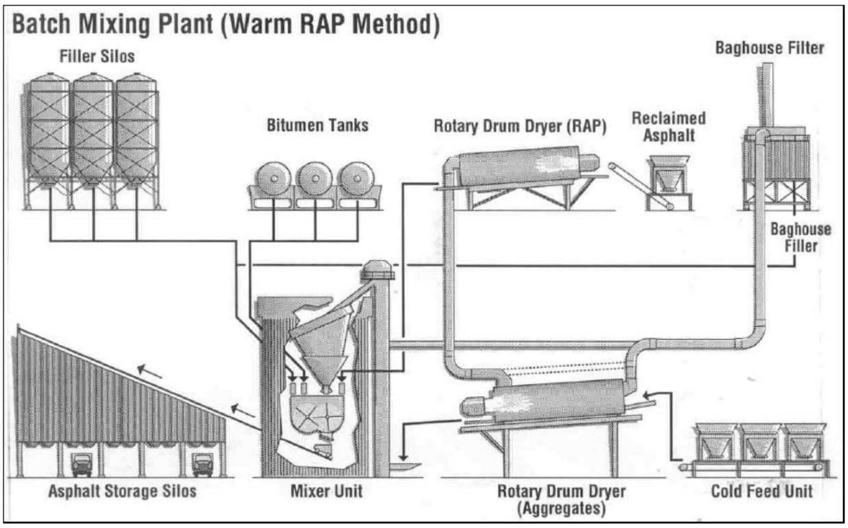

Figure 27: Batch Mixing Plant – Warm RAP Method (EAPA, 2007)

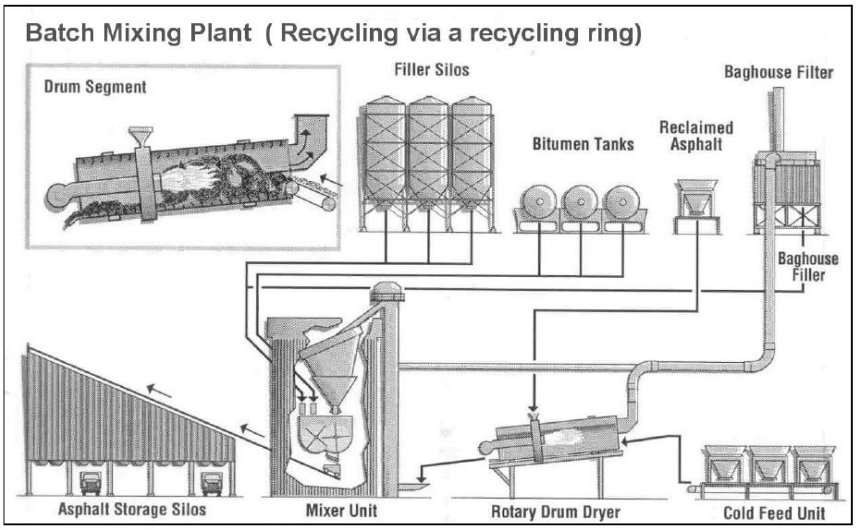

Figure 28: Batch Mixing Plant – recycling via a recycling ring (EAPA, 2007)

Another variation on hot recycling is the recycling ring system (Figure 28). In this variation the virgin aggregates and recycled material are introduced in the same drum but in two different places. The heating of recycled asphalt takes place behind the flame, ensuring that the recycled materials do not become overheated. This method allows 35-50% recycling depending on the system (EAPA, 2007).

4.2.2 Technique

In plant recycling requires the transport of reclaimed road material from the source site to the mixing plant. In countries with dense distribution of stationary mixing plants, transport distances may be below 50 km. For larger construction sites the setup of mobile mixing plants is an option if plant-mixing shall be applied.

The recycling of reclaimed road materials in mixing plants demands for a sophisticated quality control of the source materials for the new asphalt mixes. Therefore, the reclaimed road material is characterized before it is delivered to the mixing plant. Depending on the mixture type (cold, warm or hot-mixed) several parameters needed for mix design shall be evaluated.

The most important properties to be evaluated are:

- maximum RA grain size U [mm];
- binder content [%];
- content of foreign matter;
- grading of aggregates;
- properties of binder (penetration value or ring and ball temperature).

Additionally the type of aggregates as well as aggregate characteristics shall be specified if requirements are defined for the resulting asphalt mix (e.g. surface asphalt mixtures). Besides the mean value of these characteristics, its homogeneity in the RA used for preparing the asphalt mixture is of importance.

Some countries only apply specifications on the final asphalt mix. In these cases the contractor has to ensure the suitability of the final mix and may introduce some internal quality control.

As the homogeneity of the reclaimed material is important for the homogeneity of the resulting asphalt mixture, several samples should be taken to evaluate the properties of RA coming from one source in the mixing plant (e.g. one stockpile). EN 13108-8 specifies to analyse at least 1 sample for 500 t but at least 5 samples of RA material if an addition to hot-mix asphalt of more than 20% (10% for surface asphalt mixes) is planned. For smaller recycling rates at least 1 sample for 2.000 t is required. These sampling procedures are applied practically in most European countries.

In addition to the composition of the RA, the water content has an important role for the further recycling process as it can reduce the percentage of addition in hot-mix asphalt with cold-feed techniques. The water content also is to be considered for cold-recycling mix design (Direct-MAT, 2013-a).

The general design of the mixing plant influences the applicability as well as the possible use of reclaimed material during the production of hot mix asphalt.

Generally three types of mixing plants are in use for which further modular machinery may allow higher recycling rates (Direct-MAT, 2013-b):

- Continuos drum mixing plants;
- Batch plants;
- Conti-mix plant additional parallel drum.

4.2.2.1 Hot Recycling

Recycling of RA in new hot asphalt mixtures is a common re-use technique for recycled asphalt material. Technical requirements for RA and for mix design procedures are well described in EN 13108 series. Therefore, the recycling of RA in new hot-mix asphalt is widely applied throughout Europe (according to statistics of European Asphalt Pavement Association EAPA) in 2008 approx. 57% of all RA was recycled in hot-mix asphalt.

In general, HMA with addition of RA has to fulfil the same technical specifications as HMA without recycled material. The HMA with RA can be applied in new wearing courses, binder courses and base courses. As in most countries the HMA containing RA should be technically equal to HMA without any reclaimed material, it is therefore applicable on heavy trafficked roads as well.

The technically possible content of RA depends on:

- mix design:
  - type of new mix;
  - RA properties (aggregate grading, binder viscosity and modification);
  - RA homogeneity.
- mix production:
  - design of mixing plant (e.g. capacity, additional RA parallel drum, RA feeding units);
  - feeding technique (cold-feed, hot-feed);
  - water content of RA.

The recycling process occurs mainly in stationary plants, but mobile plants can be used for production near stockpiles and construction sites. The general design of the mixing plant influences the possible use of reclaimed material during the production of hot mix asphalt. Generally three types of mixing plants are in use for which further modular machinery may allow higher recycling rates.

- Batch plants (most widely used):
  - Heating reclaimed asphalt indirectly through contact with hot mix of stone fractions in the mixer (charge addition - maximum RA content ~30%): as RA is added cold directly into the mixer, it is heated indirectly only during the mixing time. Therefore, no machine parts get in contact with hot RA which prevents sticking problems;
  - Heating reclaimed asphalt indirectly through contact with hot mix of stone fractions (continuous addition - maximum RA content ~30%): RA is added to the aggregates after they are heated. Thereby, no hot sieving of the virgin aggregates is possible;
  - Heating reclaimed asphalt together with hot mix of stone fractions (maximum RA content ~20%): as RA is heated in the same counter-flow heating drum as the aggregates, this may provoke an intense aging of the RA binder. Aggregates can't be sieved after heating.
  - Separate heating of reclaimed asphalt and hot mix of stone fractions (parallel RA heating drum with maximum RA content of ~60% or counter-flow RA heating drum with maximum RA content of up to 100%): RA heating in a separate parallel drum allows gentle heating to avoid excessive binder aging. Use of RA with PMB may cause sticking problems.
- Continuous drum mixing plants (maximum RA content ~25%): the RA is heated in the same drum mixer as the aggregates but this may provoke an intensive aging of the RA binder.
- Conti-Mix plants with additional parallel drum (maximum RA content up to 100% for counter-flow heating drum, ~60% for parallel RA heating drum): as RA and the virgin constituents are added in separate material flows to the mixer, this allows the gentle heating of the RA.

Moisture content in RA should be as low as possible. To allow a constant mixing process the water content of RA shall be constant. On large exposed stockpiles the typically observed moisture content is about 3-5%. It is advisable to keep the RA as dry as possible especially when heating RA indirectly with hot mix of stone material. When RA with higher moisture content is introduced to the mixer, the capacity of asphalt plant can decrease significantly.

RA containing modified binder may cause sticking problems in the mixing process. Therefore, cold addition of this material may be feasible. For hot addition of RA containing modified binders, the mixing with RA containing unmodified binder (the ratio 1/3 PMB + 2/3 unmodified binder) can be applied in order to avoid sticking problems.

When RA is introduced by a parallel drum, the capacity of asphalt plants can increase about 30%. as more heating capacity is available. On the other hand, when cold reclaimed asphalt is introduced in the mixer, the heating of the RA indirectly by hot aggregates requires longer mixing times and therefore, the capacity of the plant can decrease about 20%.

To disintegrate the RA entirely, a prolongation of the mixing time from 5 to 10 sec is usually applied when RA is added at high recycling rate (Direct-MAT, 2013-a).

4.2.2.2 Warm Recycling

Warm Mix Asphalt refers to technologies that allow a reduction of the temperature at which asphalt mixes are produced. WMA is an asphalt that is produced and applied at temperatures roughly between 100 and 150 °C - at a temperature around 20 - 40 °C lower than an equivalent Hot Mix Asphalt that is mixed at temperatures roughly between 120 and 190 °C. The most important part of the energy needed, and thus consumed, for coating the aggregates being due to the latent heat of water evaporation. Asphalt mixes produced between approximately 70 °C and roughly 100 °Care usually considered separately and termed Half Warm Mixes.

The benefits expected from this temperature reduction are threefold:

- Environmental benefits
  - Reduced emissions:
    - 30 to -40% CO_2 and SO_2;
    - 50% VOC (volatile organic compounds);
    - 10 to -30% CO (carbon monoxide);
    - 60 to -70% NO_x (nitrous oxides);
    - 20 to -25% dust.
  - Reduced fuel consumption up to -35%.

- Safety benefits
  - Reduced exposure for workers;
  - Reduced steam (rain while paving).

- Paving benefits (for the same requirements than a HMA)
  - Improved compactibility;
  - Longer haul distance;
  - Extended paving season;
  - Reduced traffic closing time after compaction;
  - Reduced binder ageing (ability to incorporate more RA with aged binder).

The numerous WMA proprietary processes available can be broadly classified in two types according to the technology used: processes using additives and binder foaming processes.

- processes using additives

Organic additive, generally microcrystalline wax, with melting point ranging from 90 to 100°C is blended with the binder. It acts as a flow improver because at temperatures higher than 120-130°C it tends to lower the dynamic viscosity of the asphalt binder without affecting the properties of the paved layer at ambient temperature. Instead of organic additive, some processes use chemical additive acting as surfactant in order to lubricate the mix.

- binder foaming processes

A small amount of water is added during the mixing process either through hydrophilic material (zeolite) or a foaming nozzle. The water dispersed in the hot asphalt expands as steam to create bituminous foam which reduces the viscosity of the mix. Some processes include a sequential mixing: the heated aggregate is first coated with a soft binder and then mixed with a foamed hard binder.

The main concerns regarding the performances are moisture damage susceptibility, due to possibly entrapped water, and rutting resistance with respect to the reduced short term aging of the binder. The fatigue and low temperature properties (brittleness) are also specific concerns for the wax additives processes. Another problem is the laboratory evaluation and, particularly for the foaming processes, how to realistically mimic the processes in lab.

Reduced consumption of non-renewable fossil fuels and GHGs the lower mixing temperatures required to manufacture WMA consumes less energy for heating during asphalt production. The reduced consumption of burner fuel conserves non-renewable fossil fuels and reduces GHGs. Investigations carried out in several countries show significant reductions in emissions of carbon dioxide (CO_2) and nitrous oxide (NOx), while the emissions of sulphur dioxide (SO_2) and VOCs (volatile organic compounds) varied above and below those of HMA. Reuse of by-products which would otherwise require disposal although most of WMA additives are produced specially for WMA, some, such as Fischer-Tropsch waxes are produced as a by-product of the Fischer-Tropsch process and, if not used, may become a waste material. Using these products therefore has a direct environmental benefit in reducing waste materials and also pollution from the production of other WMA specific additives. Increased potential for recycling reclaimed asphalt The increased potential for recycling RA in WMA over HMA is discussed below as an economic benefit, but is listed here also as an environmental benefit since RA reduces the volume of waste material that would otherwise have to be disposed of, extracts the highest value from the RA and reduces the quantity of virgin aggregate (a non-renewable resource) and bitumen required for new asphalt layers.

Improved conditions for workers and neighbouring communities The reduced fuel burned at the mixing plant, and the lower mix temperatures during production and paving reduce emissions of aerosols, fumes and dust, both at the mixing plant and the paving site, and improves conditions for both the workers and the neighbouring communities.

Investigations into emissions at paving sites in the USA found that where temperatures were reduced by 29°C to 43°C, the average reduction in total particulate matter (TPM) was between 67% and 77%, while the asphalt fumes, measured as benzene-soluble matter (BSM), was reduced by between 72% and 81%, compared to the HMA control. General worker safety is improved as a direct result of lower asphalt temperatures that reduce the risk of heat related injuries. At the paving site, a reduction in mix temperature of 30°C in South Africa's hot summer months is very noticeable and welcomed along with the reduced odours produced by the mix.

The engineering and economic benefits of using WMA derive mainly from three aspects.

- All WMA technologies have to provide better asphalt mix workability than HMA to achieve the required compaction at lower temperatures;
- WMA's lower mixing and compaction temperatures, compared to HMA, result in flatter thermal gradients between the mix and both ambient and road temperatures. WMA therefore takes longer to cool from mixing to compaction temperature than HMA, thus providing a longer "compaction window" resulting in many engineering advantages over HMA;
- WMA's lower mixing temperatures result in comparatively less binder ageing during mixing and paving than HMA.

Several ways to produce WMA have been developed and these are briefly discussed below. The number of WMA technologies is, however, likely to increase as WMA becomes the preferable method of producing asphalt. It should be noted that while an "additive" may be used to reduce the temperature at which asphalt can be manufactured and handled, the term "WMA Technology" is used to embrace the full scope of a particular temperature-reducing process.

The aim of WMA technologies is essentially to enable proper aggregate coating and mix workability at lower temperatures by lowering the viscosity of the binder (or through other mechanisms, for example the reduction of surface tension). However, there could be other spinoffs, such as the improvement of adhesion, resistance to rutting, as well as the mix's stiffness and fatigue properties.

WMA technologies may be incorporated as ready-to-use binders or may be added during the mixing process. Two essential quality aspects apply to the ready to mix binders; homogeneity and storage stability. In the case of WMA technologies that are added to the binder, homogeneity is most important to ensure consistent quality.

WMA technologies may be conveniently divided into the following broad categories: Water technologies, Chemical additives.

Equipment to produce foamed bitumen may be installed on both batch and continuous drum mixing plant types. The systems obviously operate differently; in batch plants the foam system generates foamed bitumen for each batch whereas in a continuous drum mixer type plant the generation of foamed bitumen is continuous.

Water bearing chemical additives, which are in powdered form, can be added manually into the pugmill of batch type mixers. In the case of continuous drum mix type plants, the powder, which is normally added at a rate of around 0.3% by mass of the mix, can be added through the filler system, or by intruding it through the RA collar. It can also be introduced into the mixing drum using the pneumatic system used for feeding the cellulose fibre used in some asphalt mixtures.

Both rheological modifier and chemical additive types of WMA technologies that are blended into the binder are added through the mixing plant's normal binder addition system. In the case of batch plants the binder is usually pumped into a weigh pot before being introduced through a spraybar into the pugmill. In most continuous type drum mixing plants, the binder is introduced into the mixing drum by means of a volumetrically calibrated pumping system.

Both basic type of asphalt mixing plant should have the following monitoring and control systems:

- Binder storage tank heating temperature;
- Integrated individual cold feed hopper (virgin aggregate and RA) and burner fuel flow system;
- Burner fuel flow meter;
- Infrared skip temperature monitor;
- Infrared silo discharge temperature monitor.

Foaming systems should include integrated flow metering and pressure sensing systems for both the binder and the water used to produce the foam (SABITA, 2011).

Nowadays, for health and environmental reasons and because of high energy prices, means of lowering asphalt production temperatures are under strong development in the asphalt industry. Different methodology is used among these techniques. In this text terms warm mix and low temperature asphalt are used and they mean the same. However, it should be noted that warm mix technology is different to cold mix technology.

Lowering the temperature of the asphalt mix also has significant impact on the emissions and fumes. Tests indicate that the energy consumption in the production process can be reduced by 10 kWh/tonne of asphalt (equivalent 1 litre Oil/tonne of asphalt) if the mix temperature is lowered 35oC. In addition to fewer emissions, less fumes and less energy consumption, other advantages of Warm Asphalt are less wear of the asphalt plant, less aging of the binder and earlier opening of the road for traffic. However this product could be more expensive due to the additives, etc. and the technique is still developing.

In principle, there are several methods for the production of low temperature asphalt. These methods are based on process engineering, aerogenous agents or special bitumen and additives. Usually implementing these methods won't require large technical changes to the plant. In most cases changes are limited to adding a foaming unit or extra silos (EAPA, 2007).

5 Analysis of the Construction Process

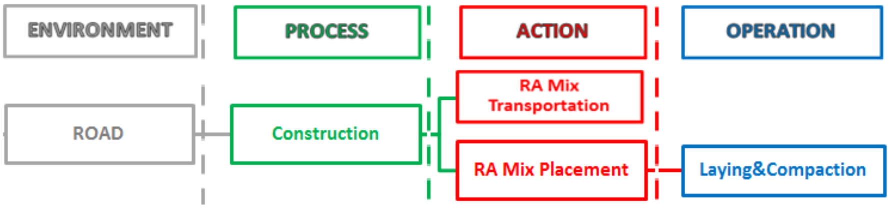

Figure 29: Partial Frame work-Construction

5.1 RA Mix Transportation

The number of haul trucks should be planned so that the transport rate matches the paving rate, thus ensuring a constant supply for the paving job site.

The following factors should be taken into consideration:

- Haul distance and haul time;
- Traffic holdups, e.g.:
  - other construction sites;
  - Traffic jams occurring every day at certain times (e.g. rush hour traffic);
  - Detours that are required due to weight limits for bridges and certain road sections;
  - Heavy and/or unpredictable traffic (congestions and detours);
  - Rest periods for drivers.

The following points should be taken into consideration for mix delivery (DAV, 2011):

- Select weight, size and type of the trucks to match the conditions on site. Vehicles with half-round trailers are the best choice;
- The truck bed of the haul truck is to be thoroughly cleaned. Only use release agents that are suited for asphalt when spraying the truck bed or bitumen impregnated crushed aggregate/sand mixtures. Make sure that there is no puddling when using liquid release agents;
- The use of oils, e.g. diesel oil, can cause severe damage to the asphalt layer and is thus strictly prohibited;
- The mix should not be hauled to the paving site if defects are detected visually already during loading (e.g. segregation, wrong temperature, fatting-up or dry mixes);
- All vehicles must be equipped with windproof tarpaulins; the load has to remain covered during transport and while the truck is stationary;
- Vehicles should stay as close to the paver as possible during backups.

Transport bituminous material from the mixing plant to the paving site in trucks having tight, clean, smooth beds that have been coated with a minimum amount of concentrated solution of hydrated lime and water or other approved coating to prevent adhesion of the mixture to the truck. Petroleum products will not be permitted for coating truck. If air temperature is less than 16°C (60°F) or if haul time is greater than 30 minutes, cover each load with canvas or other approved material of ample size to protect the mixture from the loss of heat. Make deliveries so that the spreading and rolling of all the mixture prepared for one day's run can be completed during daylight, unless adequate approved artificial lighting is provided. Deliver mixture to area to be paved so that the temperature at the time of dumping into the spreader is within the range specified herein. Reject loads that are below minimum temperature, that have crusts of cold unworkable material, or that have been wet excessively by rain. Hauling over freshly laid material is prohibited (UFGS 32 12 17, 2008).

5.2 RA Mix Placement

Construction issues for RA mixes are not different from issues encountered when paving with conventional HMA produced with virgin materials. However, failure to properly address processing as well as inadequate quality control (QC) of RA and an improper mixture design will significantly increase the likelihood of problems in placement and compaction of the new pavement.

No special equipment or techniques are required when placing and compacting mixtures containing RA.

High RA mixtures may require more attention than conventional mixtures due to increased stiffness as a result of RA. Achieving density with RA mixes is typically not a concern, but contractors should be aware that recycled mixtures with high RA are sometimes stiffer and/or may be produced at slightly higher production temperatures to facilitate blending of RA with the virgin materials. Like conventional mixes, compaction should be monitored using a non-destructive device calibrated to cores to ensure that adequate density is achieved (FHWA-HRT-11-021, 2011).

In instances where a new pavement is constructed, the substrate will normally consist of unbound crushed stone, or cementitious bound gravel. The application of a prime to penetrate and condition the surface of this layer is necessary.

A tack coat should be applied on top of the prime, once it has dried to ensure that there is a good bond between the granular and asphalt layers. An exception to this rule is when excessive “picking up” of the prime and tack coat occurs on the wheels of the paver and vehicles delivering asphalt, damaging the base. In all other cases a tack coat should be applied.

When the WMA is paved as an overlay on top of an existing asphalt layer, a tack coat should likewise always be applied. It is also necessary to apply a tack coat between newly paved asphalt layers, for instance between asphalt base and surfacing layers.

The paving and compaction techniques used for WMA are the same as for HMA. As the temperature of the WMA mix arriving at the paving site is typically 30°C below that of conventional HMA the paving crew usually immediately notice the lower temperature and lack of fumes and odour.

The temperature ranges for breakdown, intermediate and finish rolling will likewise be lower than for HMA and will depend on factors such as binder and WMA Technology type, layer thickness and ambient weather conditions.

About the opening to traffic the decision on how soon after paving to open the newly paved WMA to traffic is influenced by:

- Ambient weather conditions, including temperature and wind speed;
- Traffic loadings, vehicle speed;
- Asphalt layer thickness;
- Mix temperature;
- Binder properties.

As a guide, in the case of layer thickness of 50mm and less, the section can be opened to traffic once the surface temperature falls below 50°C. In the case of thicker asphalt layers it is prudent to close the section to traffic overnight.

RA Mix is subject to certain weather conditions, in a similar way to HMA.

Precipitation in the way of rain or drizzle, the ambient temperature, as well as the wind speed, all need to be taken into account as they do with HMA.

The wind speed and temperature affect the rate of cooling of the material, with higher wind speeds, and cold temperatures causing the most rapid decrease in material temperatures. The material thick-ness will also influence the rate of cooling, with thin layer thicknesses in cool, windy conditions being influenced most strongly;

Rain will obviously cause the asphalt layer to cool rapidly and the water may also enter the material before the asphalt is fully compacted. The manual covers the rapid cooling effect of water sprayed by the sprinkler systems onto the roller drums and tyres. This effect can be greatly remedied by the use of release agents mentioned elsewhere in this document, as this enables the volume of spray water to be significantly reduced.

The quality assurance of WMA at the paving site is the same as that required for HMA, and demands that the following be monitored:

- The substrate on which the WMA is to be paved. Granular base layers shall be properly compacted with a well-knit surface texture. The surface shall be primed and a tack coat applied before paving the WMA. Asphalt surfaces shall be tacked before the WMA layer is paved;
- The temperature of the mix on arrival at the paver. This entails measuring and recording the temperature of each truckload of WMA as the mix is tipped into the paver hopper;
- The compaction of the asphalt layer. Process control is normally carried out using a nuclear gauge during the final stages of compaction, while acceptance control is undertaken on core samples taken the next day. The cores are also utilised in checking layer thickness.

Other measurements to ascertain whether the layer conforms to the specified construction tolerances and finish requirements, such as level and grade, cross section, and surface regularity are also taken on the completed asphalt layer (SABITA, 2011).

6 End User Manual Type

In this part, the methodology of drafting the RA End-Users Manual is widely descripted.

Since the overall RA recycling process, from the dismantling of old pavements to the reuse within new pavements, is complex and several users have specific roles and objectives, it seemed most practical to use tailored check-lists for each user that summarise all actions to be implemented to achieve the purposes.

According to the framework of process shown in paragraph 2, the so-called Process Paths were defined as a sequence of actions, having as initial action the demolition and as ultimate the paving and compaction (Figure 30). The number of such paths depends on the technically allowable combinations of the various actions. Every action is identified by choosing only one operation amongst the different options.

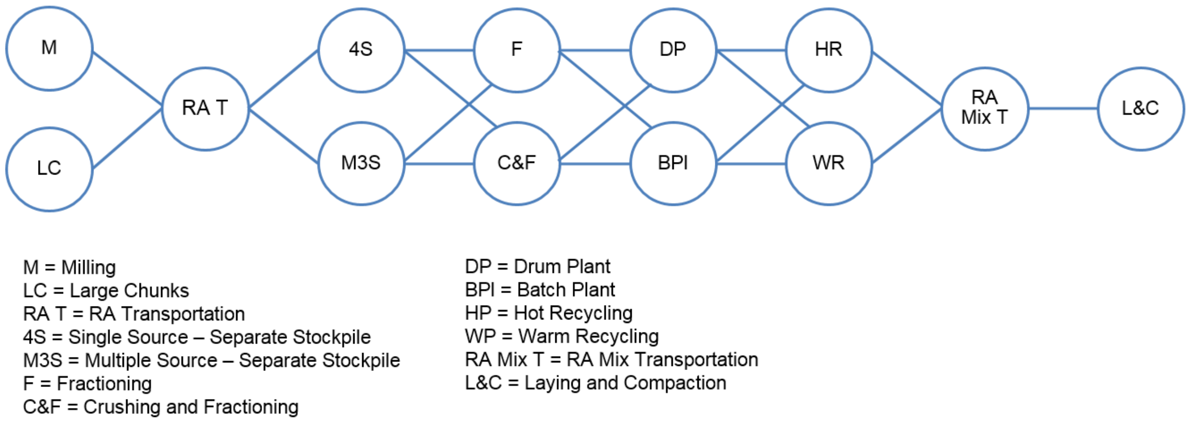

Figure 30: Sequence of all operations

Bearing in mind that the RA users are identified in the road agency, with a peculiar role of control and supervision, the plant company, with a crucial role in achieving RA high quality and finally the construction enterprise, the matrix USER/OPERATION was built by crossing the specific operation (row) with the user directly concerned (column) (Table 4).

Based on this distribution of roles and responsibilities, the three following general Check Lists, one for each user, were composed (Table 5, Table 6, Table 7 and Table 8).

The structure of the Checklist provides for each Operation, the Basic Rule, required in order to perform well each step of the process. The type of rule can be identified by a regulatory requirement (Regulation, R), a prescription contract (Specification, S), and a good practice (Best Practices, BP).

At the right side, the last column is the response column, necessary for subsequent evaluation of the reliability of the followed process path.

Obviously, every checklist contains the entire option range (all the possible operations relative to a single action).

The overall checklist of a generic process path will be composed by adding up the single checklist with only one operation per action.

Table 4: USER/OPERATION Matrix

USER/OPERATION MATRIX			
USER OPERATION	**ROAD AGENCY**	**PLANT COMPANY**	**CONSTRUCTION ENTERPRISES**
Milling	●		●
Large Chunks	●		
RA Transportation			●
Single Source – Separate Stockpile	●	●	
Multiple Source – Separate Stockpile	●	●	
Fractioning		●	
Fractioning & Crushing		●	
Drum Plant		●	
Batch Plant		●	
Hot Recycling		●	
Warm Recycling		●	
RA Mix Transportation	●		●
Laying & Compaction	●		●

Table 5: Check List Road Agency

OVERALL CHECK LIST ROAD AGENCY				
OPERATION	**BASIC RULE (CODE)**	**TYPE OF RULE**	**DESCRIPTION**	**DONE (YES/NOT)**
Milling	Selection the milling depth (M-SMD1)	BP	Based on examination of pavement cores. Frequency of the cores is 1set/km×lane on highway; 1set/block×lane on street. One set is composed by 3 cores along cross section at least	
Milling	Check the Operations led by the Enterprise (M-COE1)	S	Verifying the required milling depth	
Milling	Check the Operations led by the Enterprise (M-COE2)	S	Verifying the required pavement area to be dismantled	
Large Chunks	Selection the Thickness of Pavement to be dismantled (LC-STP1)	BP	Based on examination of pavement cores. Frequency of the cores is 1set/km×lane on highway; 1set/block×lane on street. One set is composed by 3 cores along cross section at least	
Large Chunks	Check the Operations led by the Enterprise (LC-COE1)	S	Verifying the required milling depth	
Large Chunks	Check the Operations led by the Enterprise (LC-COE2)	S	Verifying the required pavement area to be dismantled	
Single Source Separate Stockpiles	making RAP Quality Control Plan (4S-QCP1)	BP	Determining the RAP gradation by regular test (for replenishing stockpiles). Frequency is one test/1tons at least	
Single Source Separate Stockpiles	making RAP Quality Control Plan (4S-QCP2)	BP	Determining the RAP binder content by regular test (for replenishing stockpiles). Frequency is one test/1tons at least	
Single Source Separate Stockpiles	making RAP Quality Control Plan (4S-QCP3)	BP	Determining the RAP bulk specific gravity by regular test (for replenishing stockpiles). Frequency is one test/1tons at least	
Multiple Source Separate Stockpiles	making RAP Quality Control Plan (M3S-QCP1)	BP	Determining the RAP gradation by regular test (for replenishing stockpiles). Frequency is three test/1tons at least	
Multiple Source Separate Stockpiles	making RAP Quality Control Plan (M3S-QCP2)	BP	Determining the RAP binder content by regular test (for replenishing stockpiles). Frequency is three test/1tons at least	
Multiple Source Separate Stockpiles	making RAP Quality Control Plan (M3S-QCP3)	BP	Determining the RAP bulk specific gravity by regular test (for replenishing stockpiles). Frequency is three test/1tons at least	
RA Mix Transportation	Checking Transportation Time (RAMT-CHTT1)	BP	Measuring the time between plant and site (in average maximum 90mins)	
Laying & Compaction	Testing RAP Quality of the Laying and Compaction (LC-TQ1)	S	Probing of the pavement and testing on the cores. Frequency of the cores is 1set/km×lane on highway at least; 1set/block×lane on street at least. One set is composed by 3 cores along cross section at least	

Table 6: Check List Plant Company-Part 1

OVERALL CHECK LIST PLANT COMPANY				
OPERATION	**BASIC RULE (CODE)**	**TYPE OF RULE**	**DESCRIPTION**	**DONE (YES/NOT)**
Single Source Separate Stockpiles	Storage Area (4S-SA1)	BP	Minimum area should be not less than 1500 m^2. Area should be sloped (six degree is ideal)	
Single Source Separate Stockpiles	Storage Area (4S-SA2)	BP	Treatment of the surface area (no water, no clay)	
Single Source Separate Stockpiles	Storage Area (4S-SA3)	BP	Permeable to air roof with permeable to air membrane	
Single Source Separate Stockpiles	Stockpiling (4S-S1)	BP	Stockpile must have conical shape with maximum height of 6 m	
Single Source Separate Stockpiles	Stockpiling (4S-S2)	R	Searching for deleterious materials (EN 12697-42) Sampling according to EN 932-1	
Single Source Separate Stockpiles	Stockpiling (4S-S3)	R	Determining aggregate grading (EN-13043) Sampling according to EN 932-1	
Single Source Separate Stockpiles	Stockpiling (4S-S4)	R	Determining binder content (EN 12697-1) Sampling according to EN 932-1	
Multiple Source Separate Stockpiles	Storage Area (M3S-SA1)	BP	Minimum area should be not less than 1500m^2. Area should be sloped (six degree is ideal)	
Multiple Source Separate Stockpiles	Storage Area (M3S-SA2)	BP	Treatment of the surface area (no water, no clay)	
Multiple Source Separate Stockpiles	Storage Area (M3S-SA3)	BP	Permeable to air roof with permeable to air membrane	
Multiple Source Separate Stockpiles	Stockpiling (M3S-S1)	BP	Stockpile must have conical shape with maximum height of 6 m	
Multiple Source Separate Stockpiles	Stockpiling (M3S-S2)	R	Searching for deleterious materials (EN 12697-42). Sampling according to EN 932-1. Number of samples equal to 1.5 of number of samples according to EN 12697-42 and EN 932-1	
Multiple Source Separate Stockpiles	Stockpiling (M3S-S3)	R	Determining aggregate grading (EN-13043). Sampling according to EN 932-1. Number of samples equal to 1.5 of number of samples according to EN 13043 and EN 932-1	
Multiple Source Separate Stockpiles	Stockpiling (M3S-S4)	R	Determining binder content (EN 12697-1). Sampling according to EN 932-1. Number of samples equal to 1.5 of number of samples according to EN 12697-1 and EN 932-1	

Table 7: Check List Plant Company-Part 2

OVERALL CHECK LIST PLANT COMPANY				
OPERATION	**BASIC RULE (CODE)**	**TYPE OF RULE**	**DESCRIPTION**	**DONE (YES/NOT)**
Fractioning	Number of Screening (Sieves) Unit (F-NSU1)	BP	The Plant must have 3 screening unit at least, typically 3/4, 3/8, 3/16 (ASTM series or equivalent)	
Crushing & Fractioning	Preliminary Screening (CF-PS1)	BP	Preliminary screening of the finer particles by a suitable sieve (3/16 ASTM series or equivalent)	
Crushing & Fractioning	Before & After analysis of RAP gradation (CF-BAG1)	BP	Gradation control before & after the in line crusher to determine the RAP aggregate size (within 1B&A analysis 2 samples for RAP source)	
Crushing & Fractioning	Number of Screening (Sieves) Unit (CF-NSU1)	BP	The Plant must have 3 screening unit at least, typically 3/4, 3/8, 3/16 (ASTM series or equivalent)	
Drum Plant	Mixing RAP (DP-MRAP1)	BP	The plant must have split feed drum mixer	
Drum Plant	Mixing RAP (DP-M2)	BP	The plant must have double barrel drum mixer	
Drum Plant	Mixing RAP (DP-M3)	BP	The plant must have counterflow drum mixer	
Batch Plant	Drying RAP (BP-D1)	BP	The plant must have a tandem rotary drum dryer (T=110÷130°C)	
Batch Plant	Drying RAP (BP-D2)	BP	The plant must have a rotary drum dryer with recycling ring (T=110÷130°C)	
Hot Recycling	Heating Temperature Control (HR-HTC1)	BP	Verifying the heating temperature of RA is within the range 110÷130°C	
Hot Recycling	Mixing Time Control (HR -MTC1)	BP	Verifying the mixing time is within the range 25÷90 s	
Hot Recycling	Emission Control (HR-EC1)	R	Verifying the pollutant emission according to UE Directive 75/2010	
Warm Recycling	Heating Temperature Control (WR-HTC1)	BP	Verifying the heating temperature of RA is within the range 110÷130°C	
Warm Recycling	Mixing Time Control (WR-MTC1)	BP	Verifying the mixing time is within the range 25÷90 s	
Warm Recycling	Emission Control (WR-EC1)	R	Verifying the pollutant emission according to UE Directive 75/2010	
Warm Recycling	Addition Systems for Plant (WR-ASP1)	BP	In the case of use of foam bitumen as additive it's needed to implement with a foaming unit or extra silos	

Table 8: Check List Construction Enterprise

OVERALL CHECK LIST CONSTRUCTION ENTERPRISE				
OPERATION	**BASIC RULE (CODE)**	**TYPE OF RULE**	**DESCRIPTION**	**DONE (YES/NOT)**
Milling	Control Fine Content (M-CFC1)	BP	Minimizing fines content (slow forward speed or fast drum rotation will generate more undesirable fines)	
Milling	Contamination Control (M-CC1)	BP	Making sure the milled material is not contaminated with soil, base material, paving geotextiles, or other debris (maximum 1%)	
RA Transportation	Truck Maintenance (RAT-TM1)	BP	Cleaning the truck beds before hauling millings or useable RA	
RA Transportation	RA Dumping (RAT-D1)	BP	Clearly instructed where to dump loads	
RA Mix Transportation	Truck Selection (RAMT-TS1)	BP	Selecting weight, size and type of the trucks to match the conditions on site	
RA Mix Transportation	Truck Maintenance (RAMT-TM1)	BP	Cleaning the truck bed with suitable agents. (Use of oils, e.g. diesel oil is strictly prohibited)	
RA Mix Transportation	Loading Control (RAMT-LC1)	BP	During loading visually verifying defects (e.g. segregation, wrong temperature, fatting-up or dry mixes)	
RA Mix Transportation	Truck Equipment (RAMT-TE1)	BP	Equipping all vehicles with windproof tarpaulins	
Laying & Compaction	Testing RAP Quality of the Laying and Compaction (LC-TQ2)	S	Measuring the temperature at the beginning of the laying (in minimum average value 140°C for HMA; in minimum average value 110°C for WMA)	
Laying & Compaction	Environmental Condition Checking (LC-ECC1)	BP	For WMA no laying and compacting if wind speed is more than 10 km/h and temperature is last than 10°C	
Laying & Compaction	WMA Compaction (LC-WMAC1)	BP	For WMA reducing the effort compaction (number of passage and/or loading wheel) compared to HMA	

As can be seen, the set of the basic rules are quite large. In order to evaluate the quality of the generic process path, a basic rule can be weighted depending on the category (Regulation, R; Specification, S; Best Practices, BP) to which it belongs. The weights may be set conventionally as shown in Table 9, by setting a descending hierarchy that goes from R to BP.

Table 9: Numerical Criterion for Basic Rule

TYPE OF RULE	R	S	BP
WEIGHT VALUE (WV)	3	2	1

To assess the reliability of the generic path, the REliability Measure parameter (REM) was defined as follows:

$$REM = \sum_{i=1}^{n} WV_{[BRi=YES]}$$

Where:

n is the total number of the basic rules of the given path;

WV $[BR_i$=yes] the value, varying from 1 to 3, of the i^{th} basic rule put in place.

The reliability of the generic path is calculated by dividing REM to the maximum achievable REM, i.e. when the checklist is populated with all its positive answers.

It then defines the coefficient of reliability “Reliability Ratio” (RR) varying from 0 to 1, as:

$$RR = \frac{\sum_{i=1}^{n} WV_{[BRi=YES]}}{\sum_{i=1}^{n} WV_{[AllBRi=YES]}}$$

Where:

WV [AllBR$_i$=yes] is the maximum value of the REM.

By way of example, here are the complete checklists of four process paths (Table 10, Table 11, Table 12 and Table 13).

Table 10: Process Path 1

CHECK LIST RA PROCESS - PATH 1												
USERS ACTIVITIES: REGULATIONS SPECIFICATIONS AND BEST PRACTICES												
OPERATION	ROAD AGENCY				PLANT COMPANY				CONSTRUCTION ENTERPRISE			
	BASIC RULE (CODE)	TYPE OF RULE	DONE (YES/NOT)	WEIGHT VALUE	BASIC RULE (CODE)	TYPE OF RULE	DONE (YES/NOT)	WEIGHT VALUE	BASIC RULE (CODE)	TYPE OF RULE	DONE (YES/NOT)	WEIGHT VALUE
Milling	M-SMD1	BP		Weight/0					M-CFC1	BP		Weight/0
	M-COE1	S		Weight/0					M-CC1	BP		Weight/0
	M-COE2	S		Weight/0								
RA Transportation									RAT-TM1	BP		Weight/0
									RAT-D1	BP		Weight/0
From one single source - separate stockpiles	4S-QCP1	BP		Weight/0	4S-SA1	BP		Weight/0				
	4S-QCP2	BP		Weight/0	4S-SA2	BP		Weight/0				
	4S-QCP3	BP		Weight/0	4S-SA3	BP		Weight/0				
					4S-S1	BP		Weight/0				
					4S-S2	R		Weight/0				
					4S-S3	R		Weight/0				
					4S-S4	R		Weight/0				
Fractioning					F-NSU1	BP		Weight/0				
Batch Plant					BP-D1	BP		Weight/0				
					BP-D2	BP		Weight/0				
Hot Recycling					HR-HTC1	BP		Weight/0				
					HR-MTC1	BP		Weight/0				
					HR-EC1	R		Weight/0				
RA Mix Transportation	RAMT-CHTT1	BP		Weight/0					RAMT-TS1	BP		Weight/0
									RAMT-TM1	BP		Weight/0
									RAMT-LC1	BP		Weight/0
									RAMT-TE1	BP		Weight/0
Laying& Compaction	LC-TQ1	BP		Weight/0					LC-TQ2	S		Weight/0
									LC-ECC1	BP		Weight/0
									LC-WMAC1	BP		Weight/0

Table 11: Process Path 2

CHECK LIST RA PROCESS - PATH 2												
USERS ACTIVITIES: REGULATIONS SPECIFICATIONS AND BEST PRACTICES												
OPERATION	ROAD AGENCY				PLANT COMPANY				CONSTRUCTION ENTERPRISE			
	BASIC RULE (CODE)	TYPE OF RULE	DONE (YES/NOT)	WEIGHT VALUE	BASIC RULE (CODE)	TYPE OF RULE	DONE (YES/NOT)	WEIGHT VALUE	BASIC RULE (CODE)	TYPE OF RULE	DONE (YES/NOT)	WEIGHT VALUE
Milling	M-SMD1	BP		Weight/0					M-CFC1	BP		Weight/0
	M-COE1	S		Weight/0					M-CC1	BP		Weight/0
	M-COE2	S		Weight/0								
RA Transportation									RAT-TM1	BP		Weight/0
									RAT-D1	BP		Weight/0
From multiple source - separate stockpiles	M3S -QCP1	BP		Weight/0	M3S -SA1	BP		Weight/0				
	M3S -QCP2	BP		Weight/0	M3S -SA2	BP		Weight/0				
	M3S -QCP3	BP		Weight/0	M3S -SA3	BP		Weight/0				
					M3S -S1	BP		Weight/0				
					M3S -S2	R		Weight/0				
					M3S -S3	R		Weight/0				
					M3S -S4	R		Weight/0				
Fractioning					F-NSU1	BP		Weight/0				
Batch Plant					BP-D1	BP		Weight/0				
					BP-D2	BP		Weight/0				
Hot Recycling					HR-HTC1	BP		Weight/0				
					HR-MTC1	BP		Weight/0				
					HR-EC1	R		Weight/0				
RA Mix Transportation	RAMT-CHTT1	BP		Weight/0					RAMT-TS1	BP		Weight/0
									RAMT-TM1	BP		Weight/0
									RAMT-LC1	BP		Weight/0
									RAMT-TE1	BP		Weight/0
Laying& Compaction	LC-TQ1	BP		Weight/0					LC-TQ2	S		Weight/0
									LC-ECC1	BP		Weight/0
									LC-WMAC1	BP		Weight/0

Table 12: Process Path 3

CHECK LIST RA PROCESS - PATH 3												
USERS ACTIVITIES: REGULATIONS SPECIFICATIONS AND BEST PRACTICES												
OPERATION	ROAD AGENCY				PLANT COMPANY				CONSTRUCTION ENTERPRISE			
	BASIC RULE (CODE)	TYPE OF RULE	DONE (YES/NOT)	WEIGHT VALUE	BASIC RULE (CODE)	TYPE OF RULE	DONE (YES/NOT)	WEIGHT VALUE	BASIC RULE (CODE)	TYPE OF RULE	DONE (YES/NOT)	WEIGHT VALUE
Milling	M-SMD1	BP		Weight/0					M-CFC1	BP		Weight/0
	M-COE1	S		Weight/0					M-CC1	BP		Weight/0
	M-COE2	S		Weight/0								
RA Transportation									RAT-TM1	BP		Weight/0
									RAT-D1	BP		Weight/0
From multiple source - separate stockpiles	M3S -QCP1	BP		Weight/0	M3S -SA1	BP		Weight/0				
	M3S -QCP2	BP		Weight/0	M3S -SA2	BP		Weight/0				
	M3S -QCP3	BP		Weight/0	M3S -SA3	BP		Weight/0				
					M3S -S1	BP		Weight/0				
					M3S -S2	R		Weight/0				
					M3S -S3	R		Weight/0				
					M3S -S4	R		Weight/0				
Fractioning					F-NSU1	BP		Weight/0				
Batch Plant					BP-D1	BP		Weight/0				
					BP-D2	BP		Weight/0				
Warm Recycling					WR-HTC1	BP		Weight/0				
					WR-MTC1	BP		Weight/0				
					WR-EC1	R		Weight/0				
					WR-ASP1	BP		Weight/0				
RA Mix Transportation	RAMT-CHTT1	BP		Weight/0					RAMT-TS1	BP		Weight/0
									RAMT-TM1	BP		Weight/0
									RAMT-LC1	BP		Weight/0
									RAMT-TE1	BP		Weight/0
Laying& Compaction	LC-TQ1	BP		Weight/0					LC-TQ2	S		Weight/0
									LC-ECC1	BP		Weight/0
									LC-WMAC1	BP		Weight/0

Table 13: Process Path 4

CHECK LIST RA PROCESS - PATH 4												
USERS ACTIVITIES: REGULATIONS SPECIFICATIONS AND BEST PRACTICES												
OPERATION	ROAD AGENCY				PLANT COMPANY				CONSTRUCTION ENTERPRISE			
	BASIC RULE (CODE)	TYPE OF RULE	DONE (YES/NOT)	WEIGHT VALUE	BASIC RULE (CODE)	TYPE OF RULE	DONE (YES/NOT)	WEIGHT VALUE	BASIC RULE (CODE)	TYPE OF RULE	DONE (YES/NOT)	WEIGHT VALUE
Large Chunks	LC-STP1 LC-COE1 LC-COE2	BP S S		Weight/0 Weight/0 Weight/0					M-CFC1 M-CC1	BP BP		Weight/0 Weight/0
RA Transportation									RAT-TM1 RAT-D1	BP BP		Weight/0 Weight/0
From one single source - separate stockpiles	4S-QCP1 4S-QCP2 4S-QCP3	BP BP BP		Weight/0 Weight/0 Weight/0	4S-SA1 4S-SA2 4S-SA3 4S-S1 4S-S2 4S-S3 4S-S4	BP BP BP BP R R R		Weight/0 Weight/0 Weight/0 Weight/0 Weight/0 Weight/0 Weight/0				
Crushing & Fractioning					CF-PS1 CF-BAG1 CF-NSU1	BP BP BP		Weight/0 Weight/0 Weight/0				
Drum Plant					DP-MRAP1 DP-M2 DP-M3	BP BP BP		Weight/0 Weight/0 Weight/0				
Warm Recycling					WR-HTC1 WR-MTC1 WR-EC1 WR-ASP1	BP BP R BP		Weight/0 Weight/0 Weight/0 Weight/0				
RA Mix Transportation	RAMT-CHTT1	BP		Weight/0					RAMT-TS1 RAMT-TM1 RAMT-LC1 RAMT-TE1	BP BP BP BP		Weight/0 Weight/0 Weight/0 Weight/0
Laying& Compaction	LC-TQ1	BP		Weight/0					LC-TQ2 LC-ECC1 LC-WMAC1	S BP BP		Weight/0 Weight/0 Weight/0

7 Case Study

The case studies concern the part of the process path that regards just the mixing plant due to the fact that the full scale production of RA mixes was an important and peculiar step of the undertaken research. The process parts such as provision and construction could not be considered because these phases were not performed under the author’s control. Both the Italian case and German one were analysed and evaluated through the methodology described above.

7.1 Italy

With the purposes of the corresponding project, four asphalt mixes for wearing courses were manufactured in mixing plant: 0% RA, 30% RA + Add, 60% RA + Add and 90% RA + Add respectively according to the laboratory design by SUPERPAVE method (level 1). A detailed description of the mix-design process is included in Deliverable D2.1.

The full-scale production was carried out by the main mixing plant of Ferrara Accardi & F. s.r.l. located in Catania (Sicily). This mixing plant is the largest one in Sicily for annual production of conventional asphalt, besides being one of the few mixing plants equipped with technology for the production of reclaimed asphalt.

The plant was founded to produce a maximum amount of 200 ton/h; it is of discontinuous type with drum mixer with ring recycling.

The diagram of operation of the mixing plant is shown in Figure 31.

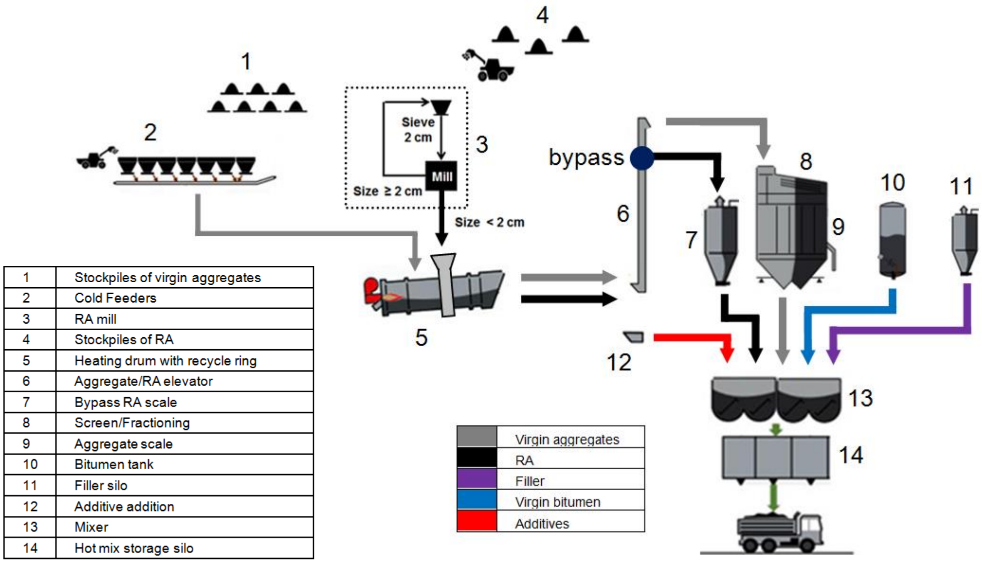

Figure 31: Scheme of Italian mixing plant

As concerns such full-scale production the RA derives from dismantled pavements with practically the same asphalt; therefore it can be assumed that the material comes from only one source.

The storage area of the RA is of about 2000 m^2; in particular the base underneath the piles is made of reinforced concrete and kept free from pollutant and water runoff.

The piles are not protected from the elements and have substantially conical shape with heights of over 5 m.

The RA coming from the storage area is preliminarily subjected to an iterative process of crushing in such a way that all the material that feeds the drum appears to have a predetermined maximum grain size (20 mm in the case of asphalt for wearing course). The further crushed RA is put, via the ring of recycling, inside a cylindrical ring, coaxial with the drum, whose insides are heated by contact with the hot aggregate in the drum itself.

The hot aggregates coming from the drum are conveyed up to the screeners dosing via a lift; the system is equipped with a bypass which allows, to convey the RA air in a silo, to not to smear bitumen sieves of the dosing system weight, which is then used exclusively for aggregates. In this manner, the dosage of the RA is via a volumetric feeder automatic interposed between mill and drum.

On the basis of the framework of the plant described above, the maximum percentage of RA permitted in the production of reclaimed asphalt is directly due to the amount of stone aggregate content inside the drum; in fact, for very high percentages of RA and consequently low amount of virgin aggregate, it was impossible to achieve the mixing temperatures required; also in these conditions it is assisted to a sudden increase of the temperatures of the fumes coming from the drum.

7.1.1 Mixes production

The production was carried out on December 4th and 5th 2014.The final amount of each asphalt mixture was of about 3 tons. In order to carry out the laboratory survey about 1.2 tons (in total) were shipped to University of Dresden and 1.2 tons (in total) to University of Palermo.

The final mixture temperature was checked during the taking of asphalt from the silo.

It should be noted that the production was carried out on a day of normal operation of the plant; therefore the production of the four Italian asphalt mixtures was realised alternating with the daily commercial productions, which, on that day, did not include mixtures with reclaimed asphalt.

The mixtures with RA were carried out with the addition of an additive (mix of rejuvenator and warm mix additive, explained in detail in Deliverable D2.1); this has allowed to maintain the mixing temperature on ordinary values even for the mixtures with the highest RA percentage.

The mixing temperatures are reported in Table 14 provided for each of the blends produced.

Table 14: Mixing temperature target of Italian mixes

Mix	Mixing temperature target [°C]
0% RA	160
30% RA +Add.	163
60% RA + Add.	165
90% RA + Add.	170

As regards the mixtures without RA and with 30% of RA, the plant has reached easily the mixing temperatures of 158 °C and 165 °C respectively.

As regards the mixture with 60% of RA, in order to abide by the temperature limit of 200°C (temperatures above cause a damage risk of the filtering system by the fumes coming from the drum), the production was carried out by putting in the ring of recycling only 50% of the total weight of required RA, while the remaining cold part was directly sent to the mixer, once the virgin aggregate and hot RA were already put inside. Since approximately 300 kg per ton of the mixture were added to the mixture at the ambient temperature of 15°C, in order to obtain the expected mixing temperature, it was necessary to initiate an increase of the heating temperatures of the virgin aggregate and the RA. Finally, two productions have been carried out: in the first case a final mixing temperature of 158°C was achieved; in the second case, the excessive heating of the materials coming from the drum provoked a final mixing temperature of 200°C. For the purposes of the research just the mixture produced at lower temperature was considered.

As regards the mixture with 90% RA, because of the limits of the mixing plant system, it could not be reached a mixing temperature above 110°C. It is appropriate to point out that two mixing attempts were made, considering two different percentages of RA admitted cold (50% and 33% with respect to the overall quantity of RA); however, the too small amounts of virgin aggregate inside the drum (approximately 100 kg per ton of mixture) did not allow a sufficient heat exchange to ensure the attainment of temperatures necessary for the blending. In addition, the shortage of virgin material within the drum did increase the temperature of the fumes, leading it abruptly to the threshold value permitted by the system and forcing, consequently, the operator to decrease the energy of the burner of the drum. Thus all mixes were produced in plant except the one with 90% RA. The latter was then manufactured in the laboratory for the experimental survey reported in Deliverable D4.1.

7.1.2 Evaluation of the process path

In order to evaluate the technical path, following the methodology described above, the checklist reported in Table 15 hast been developed.

Table 15: Overall checklist of Italian plant

OVERALL CHECK LIST PLANT COMPANY				
OPERATION	**BASIC RULE (CODE)**	**TYPE OF RULE**	**DESCRIPTION**	**DONE (YES/NOT)**
Single Source Separate Stockpiles	Storage Area (4S-SA1)	BP	Minimum area should be not less than 1500m^2. Area should be sloped (six degree is ideal)	YES
Single Source Separate Stockpiles	Storage Area (4S-SA2)	BP	Treatment of the surface area (no water, no clay)	YES
Single Source Separate Stockpiles	Storage Area (4S-SA3)	BP	Permeable to air roof with permeable to air membrane	NO
Single Source Separate Stockpiles	Stockpiling (4S-S1)	BP	Stockpile must have conical shape with maximum height of 6 m	YES
Single Source Separate Stockpiles	Stockpiling (4S-S2)	R	Searching for deleterious materials (EN 12697-42) Sampling according to EN 932-1	NO
Single Source Separate Stockpiles	Stockpiling (4S-S3)	R	Determining aggregate grading (EN-13043) Sampling according to EN 932-1	NO
Single Source Separate Stockpiles	Stockpiling (4S-S4)	R	Determining binder content (EN 12697-1) Sampling according to EN 932-1	YES
Crushing & Fractioning	Preliminary Screening (CF-PS1)	BP	Preliminary screening of the finer particles by a suitable sieve (3/16 ASTM series or equivalent)	NO
Crushing & Fractioning	Before & After analysis of RAP gradation (CF-BAG1)	BP	Gradation control before & after the in line crusher to determine the RAP aggregate size (within 1B&A analysis 2 samples for RAP source)	NO
Crushing & Fractioning	Number of Screening (Sieves) Unit (CF-NSU1)	BP	The Plant must have 3 screening unit at least, typically 3/4, 3/8, 3/16 (ASTM series or equivalent)	NO
Batch Plant	Drying RAP (BP-D2)	BP	The plant must have a rotary drum dryer with recycling ring (T=110÷130°C)	YES
Warm Recycling	Mixing Time Control (WR-MTC1)	BP	Verifying the mixing time is within the range 25÷90 s	YES
Warm Recycling	Emission Control (WR-EC1)	R	Verifying the pollutant emission according to UE Directive 75/2010	YES

According to the responses of the checklist, the “Reliability Ratio” (RR value) is equal to 0.52.

7.2 Germany

Four asphalt mixtures for wearing courses of high volume roads of Germany (0% RA; 30% RA; 60% RA; 60% RA + Additive) were produced in plant. The designed asphalt material is a common asphalt mixture, a SMA with a nominal grain size of 8 mm (SMA 8S), and a polymer-modified bitumen (PmB 25/55-55). A detailed description of the mix-design process is included in Deliverable D2.1.

7.2.1 German plant

The production was carried out at the mixing plant of Richard Schulz Tiefbau GmbH & Co that is located in Gilching, near Munich. It is a batch type plant with a parallel drum to preheat the RA. As said before, without the parallel drum the maximum RA that can be used in batch plants finds its limits at approx. 30% due to the very high temperature needed to transfer heat from the virgin aggregates to the RA. Even if temperature and the associated emissions are not a problem, there are issues with excessive aging of the binder from the RA due to contact with superheated aggregate particles.

The diagram of operation of the mixing plant is shown in Figure 32.

The used RA, a relatively "young" asphalt, comes from one source and was stockpiled in open-air piles without fractionation. This may lead to an accelerated binder aging due to air exposure and oxidation. Furthermore, exposure to the environmental conditions will increase the moisture content in the RA resulting in high heat consumption and low thermal efficiency during mixing.

The RA coming from the storage area is preliminarily subjected to a process of crushing in such a way that all the material that feeds the drum has a given maximum size. The further crushed RA is put inside a parallel drum.

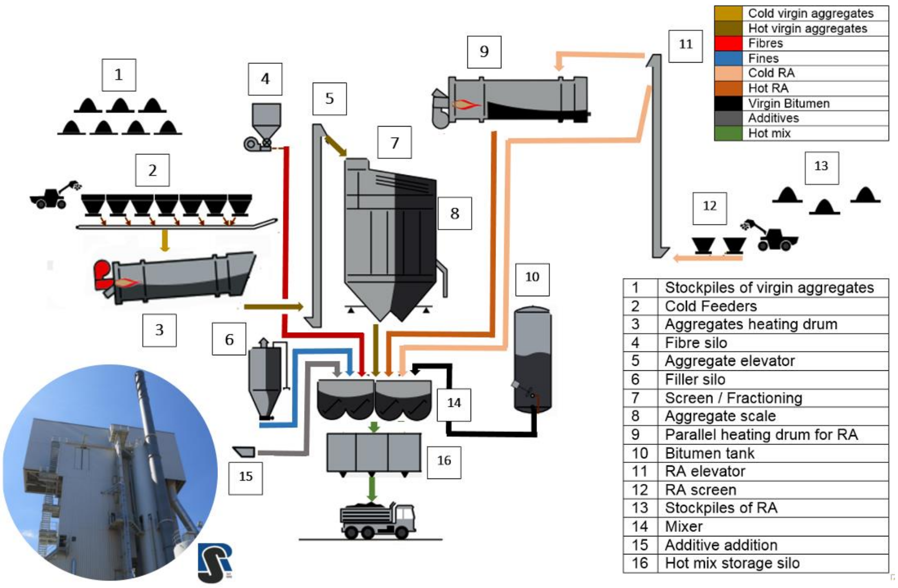

Figure 32: Scheme of German mixing plant

7.2.2 Mixes production

The production was carried out on August 8th 2014. The final produced amount of each asphalt mixture was of about 3 tons. In order to carry out the laboratory survey, presented in Deliverable D4.1, about 1.2 tons (in total) were shipped to University of Dresden and 1.2 tons (in total) to University of Palermo.

The mixing temperature was checked during the taking of the asphalt material from the silo. The temperatures are reported in Table 16 provided for each of the blends produced.

It should be noted that the production was carried out on a day of normal operation of the plant; therefore the production of the four German asphalt mixtures was realised alternating with the daily commercial productions.

One mixture with RA was produced with the addition of an additive (mix of rejuvenator and warm mix additive, explained in detail in deliverable D2.1).

Table 16: Mixing temperature target of German mixes

Mix	Mixing temperature target [°C]	Mixing temperature measured [°C]
0% RA	170	170
30% RA	170	170
60% RA	170	170
60% RA + Add.	170	165

7.2.3 Evaluation of the process path

In order to evaluate the technical path, following the methodology described above, the checklist reported in Table 17 hast been developed.

Table 17: Overall checklist of German plant

OVERALL CHECK LIST PLANT COMPANY				
OPERATION	**BASIC RULE (CODE)**	**TYPE OF RULE**	**DESCRIPTION**	**DONE (YES/NOT)**
Multiple Source Separate Stockpiles	Storage Area (M3S-SA1)	BP	Minimum area should be not less than 1500m^2. Area should be sloped (six degree is ideal)	YES
Multiple Source Separate Stockpiles	Storage Area (M3S-SA2)	BP	Treatment of the surface area (no water, no clay)	YES
Multiple Source Separate Stockpiles	Storage Area (M3S-SA3)	BP	Permeable to air roof with permeable to air membrane	NO
Multiple Source Separate Stockpiles	Stockpiling (M3S-S1)	BP	Stockpile must have conical shape with maximum height of 6 m	NO
Multiple Source Separate Stockpiles	Stockpiling (M3S-S2)	R	Searching for deleterious materials (EN 12697-42). Sampling according to EN 932-1. Number of samples equal to 1.5 of number of samples according to EN 12697-42 and EN 932-1	YES
Multiple Source Separate Stockpiles	Stockpiling (M3S-S3)	R	Determining aggregate grading (EN-13043). Sampling according to EN 932-1. Number of samples equal to 1.5 of number of samples according to EN 13043 and EN 932-1	YES
Multiple Source Separate Stockpiles	Stockpiling (M3S-S4)	R	Determining binder content (EN 12697-1). Sampling according to EN 932-1. Number of samples equal to 1.5 of number of samples according to EN 12697-1 and EN 932-1	YES
Crushing & Fractioning	Preliminary Screening (CF-PS1)	BP	Preliminary screening of the finer particles by a suitable sieve (3/16 ASTM series or equivalent)	NO
Crushing & Fractioning	Before & After analysis of RAP gradation (CF-BAG1)	BP	Gradation control before & after the in line crusher to determine the RAP aggregate size (within 1B&A analysis 2 samples for RAP source)	NO
Crushing & Fractioning	Number of Screening (Sieves) Unit (CF-NSU1)	BP	The Plant must have 3 screening unit at least, typically 3/4, 3/8, 3/16 (ASTM series or equivalent)	YES
Batch Plant	Drying RAP (BP-D1)	BP	The plant must have a tandem rotary drum dryer (T=110÷130°C)	YES
Hot Recycling	Heating Temperature Control (HR-HTC1)	BP	Verifying the heating temperature of RA is within the range 110÷130°C	YES
Hot Recycling	Mixing Time Control (HR -MTC1)	BP	Verifying the mixing time is within the range 25÷90 s	YES
Hot Recycling	Emission Control (HR-EC1)	R	Verifying the pollutant emission according to UE Directive 75/2010	YES
Warm Recycling	Heating Temperature Control (WR-HTC1)	BP	Verifying the heating temperature of RA is within the range 110÷130°C	YES
Warm Recycling	Mixing Time Control (WR-MTC1)	BP	Verifying the mixing time is within the range 25÷90 s	YES
Warm Recycling	Emission Control (WR-EC1)	R	Verifying the pollutant emission according to UE Directive 75/2010	YES

According to the responses of the checklist, the “Reliability Ratio” (RR value) is equal to 0.85.

8 Conclusions

The scope of the report was to define the guidelines of drafting of an RA End-User Manual addressed to all stakeholders such as road agencies, production plants and construction enterprises.

Preliminarily, in order both to assess the consistency of the general objectives of the corresponding research project and to realise the extent of the use of RA over European scale, a data analysis has been carried out. The main results were:

- the production of RA and its placement has shown a slightly upward trend;
- among the layers of the pavement, the wearing course is the largest "end user" of bituminous mixtures.

Thus, it is necessary to make a special effort to design asphalt mixtures with a high percentage of reclaimed asphalt for wearing course, if you want to significantly increase its amount placed. Therefore the data analysis confirms the consistency of the objectives of the current project with the purpose of the sustainability policy: the main goal was to design asphalt mixtures with high percentages of reclaimed asphalt, up to 100% of the mixture, which are able to provide performances equal to, if not superior, to the traditional ones.

In this manner it would be obtained advantages such as lower consumption of non-renewable resources such as aggregates and petroleum products, lower production costs, lower costs for maintenance and rehabilitation of the pavements, especially if the performance of such mixes were to be long lasting. In order to allow a larger RA amount within flexible pavements, it’s necessary both to change the regulation on the use of RA and to reach an harmonised regulation in the European area.

The main concept behind the idea of the End-User Manual consists of both maximising the use of RA within new road pavements and maintaining or improving the performance of the super-structure. The two main technical goals can be clearly summarised: the consensus between mixtures produced in laboratory and in plant and the achievement of the pavement performances provided by the mix design.

By the light of the complexity of the issues faced, the method of drafting an End-User Manual lies on the preparation of specific check lists rather than to include procedure and technical actions into an unique document. Such complexity depends on many factors such as the diversity of the users, of the kind of the process and then of the linked operations.

With this purpose by detailed analysis of the whole RA reuse process, from the demolition of old pavements to the RA mix placement, it was possible to draft some check lists containing the operations and linked basic rules to be followed by each user. On the basis of the specific process followed it was possible to define the so-called process path whose check list summarises all operations to be carried out with relative basic rules. According to this kind of check list the reliability of the whole process can be calculated by means of the Reliability Ratio.

As expected the stage of the process concerning the mixing plant results strategic to achieve declared goals. In fact, the basic rules for a generic process path are equal in average to 16 while the basic rules for agencies and construction enterprises are 14 and 11 respectively.

This matter is even more evident by considering the total weight value of the operations regarding the generic path: 25 for mixing plants, 11 for agencies and 12 for enterprises.

Finally this methodology was applied to the stages of production for both Italian mixing plant and German one. The results in terms of RR demonstrated that both mixing plants worked well, commenting that the German mixing plant worked with a greater accuracy.

9 Acknowledgment

The authors thank the people of Richard Schulz Tiefbau GmbH & Co and the staff of Ferrara-Accardi & F. s.r.l., in particular Dr. Francesco Ferrara, for their assistance and cooperation in the production of the asphalt mixes.

The authors also thank Dr. Noemi Pucci for her precious helping to develop the document.

The research presented in this report was carried out as part of the CEDR Transnational Road research Programme Call 2012. The funding for the research is provided by the national road administrations of Denmark, Finland, Germany, Ireland, Netherlands and Norway.

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