Chapter 2

Literature Review

2.1 Road Pavement

Roadways are the important infrastructure of the country. In Thailand, most of road pavement is flexible pavement or asphalt pavement that uses asphaltic concrete to be an adhesive material. Highways in Thailand can be categorizes in 3 types by the responsible agencies as the following:

1. Arterial Road is national highways that are responded by Department of Highways (DOH). The task for road maintenance that has distance about 62,000 km (2 lanes) is responded by Bureau of Administrative Maintenance Department of Highways.

2. Collector Road is major roadways that linked between arterial roads or linked between arterial roads and collector roads. The collector roads are responded by Department of Rural Roads (DOR). The task for road maintenance that has distance about 10,520 km (2 lanes) is responded by Bureau of Maintenance and Traffic Safety Department of Rural Roads.

3. Local Road is minor collector roads or roadways that are in the province or district that is responded by Provincial Administrative Organization (PAO).

2.2 Pavement Structure

Pavement structure consists of thin surface called wearing surface laid on base, subbase, subgrade, and natural subgrade respectively as shown in Figure 2.1:

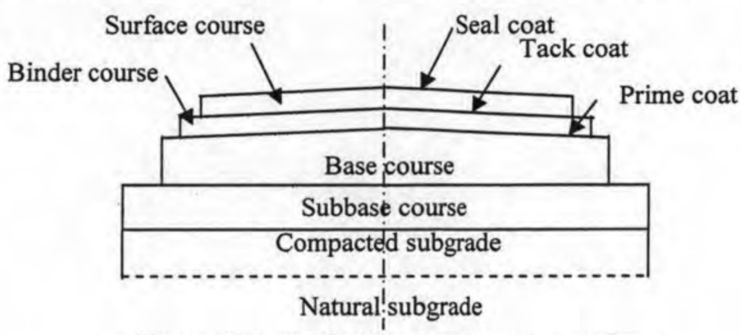


Figure 2.1 Asphaltic pavement structure

1. Wearing Surface is at the top of pavement. This surface receives load directly from wheels of vehicle. The stress occurring in the surface is very high, so the materials property used for wearing surface must be high strength and durable such as crushed stone binding with asphalt to be asphaltic concrete. The asphalt is an adhesive agent that binds crushed stone surfaces and prevents water that will be absorbed into the base course. Wearing surface can be categorized in 2 layers that consist of surface course that is at the top of pavement and binder course that is under the wearing surface and is over the base course. Wearing surface may have only surface course if the thickness of road is lower than 6 cm.

2. Base Course is layer that receives load from wearing surface and pavement shoulder. The materials property used for this surface must be high strength such as crushed stone, gravel, or granular stabilized soil.

3. Subbase Course is layer that is built in area that natural subgrade is very soft. This layer can be built by low quality materials such as granular soil or sand.

4. Selected Material is layer under subbase course, which is constructed to raise the level of road over the flood level and decreases stress in subgrade. The materials used in this layer should be easy to find and cheap.

5. Subgrade is original soil layer in area of road construction. This layer receives wheel load from base course, subbase course, and selected material. All of layers that are over subgrade are called pavement components. The thickness of pavement structure depends on the quality of subgrade.

2.3 Pavement Maintenance

When road is used for a long time, pavement deterioration will be occur due to its service life. The major causes of damages are higher traffic level, over load truck weight, and weather condition. So, it's necessary to maintain the road pavement to keep the good level of riding quality all the time. The ignorance to maintain the road pavement in appropriate time will cause the higher severe damages. In the present, DOH and DOR categorize the pavement maintenance and repair into 4 activities as following:

1. Routine Maintenance is continuously maintenance to keep the good level of riding quality all the time for users and to prevent the expansion of damages. The routine maintenance is following:

- Crack Filling
- Skin Patch
- Deep Patch

2. Periodic Maintenance is maintenance in defined time to prolong service life of road pavement. The periodic maintenance is following:

- Asphalt Seal-Coating
- Thin Asphalt Overlay

3. Special Maintenance and Rehabilitation is maintenance, modification, or improvement of road pavement that has severe damages more than repairing by normal maintenance. This type of maintenance can correct the damages into subgrade, subbase, or base depending on its condition. The special maintenance and rehabilitation are following:

- Thick Asphalt Overlay
- Pavement In-Place Recycling
- Remove Surface, Base, Replace with New Base and then Overlay

4. Emergency Maintenance is pavement repairing for suddenly damages that are unexpected events from flood, storm, or landslide that can shut down the traffic.

2.4 Pavement Maintenance Costs

Kochakorn (2000) studied the costs model in 3 types of pavement maintenance that consists of routine maintenances, periodic maintenance, and special maintenance and rehabilitation. He conclude the factor affecting pavement maintenance costs that comprises of surface condition before treatment that affect surface preparing costs, surface preparing and type of maintenance techniques, local materials prices that depends on area and physical location, and scale of the project that affect the materials prices from suppliers.

From the study of Kochakorn (2000), it can be concluded that the costs in all 3 types of pavement maintenance have 2 components that consists of fixed costs and variable cost.

1. Fixed Costs are costs that are independent from damages condition of pavement. Factors affect fixed costs, e.g. repairing technique, local materials prices, economics, site location, fuel prices, labor wage, and machine costs, etc.

2. Variable Costs are costs that depend on original damages condition before paving new asphalt. These costs can be called preparation costs. For pavement rehabilitation, there is not variable cost because the contractor has to repair the pavement damages into original pavement structure before paving new asphalt.

Prapon (2002) compared costs structure of pavement maintenance of DOH between doing by self and employing the contractor as shown in Table 2.1. It can see from Table 2.1 that when DOH employs the contractor to operate the project, the costs components that are significantly change are direct costs and indirect costs. The direct costs are changed from materials costs, labor costs, equipment costs, machine costs, and fuel costs to be wages for contractor. The indirect costs are changed from costs of operation to be costs of control and approval contractor. For the total costs estimation for employing the contractor, DOH uses standard of estimation for road construction defining as the direct costs of contractor plus the amount of money that is calculated from Factor F as the indirect cost of the contractor. The indirect costs of the contractor or operation costs of DOH are comprised of administrative costs, interest costs, profit, and VAT.

The costs of pavement maintenance in each roadway will be different by materials costs, labor costs, equipment costs, and machine costs. However, highway agencies have defined the average cost of work for planning and management the budgets for example the average cost of work in pavement maintenance of DOR in 2004 as shown in Table 2.2:

Table 2.1 Comparison pavement maintenance costs between done by self and employing the contractor.

	Done by self	Employing the contractor
Direct Costs	• Materials costs • Labor costs • Equipment costs • Machine costs • Fuel costs	• Wages
Indirect Costs	**Costs of operation**	**Costs of control and approval**
	• Salary of supervisor and secretary department • Miscellaneous costs and temporary wages • Facilities costs • Depreciation costs of machines in during no work • Depreciation costs of office and vehicles	• Salary of supervisor and secretary department • Miscellaneous costs and temporary wages • Facilities costs • Depreciation costs of office and vehicles

Source: Prapon (2002)

Table 2.2 The average cost of work in pavement maintenance of DOR in 2004

No.	List of works	Unit	Unit Price (Baht)	Operation methods
1.	Routine Maintenance			
	1.1 Crushed Stone Surface	km.	16,000	Done by self
	1.2 Asphalt Surface	km.	24,000	Done by self
	1.3 Concrete Surface	km.	9,000	Done by self
2.	Periodic Maintenance			
	2.1 Crushed Stone Overlay	km.	90,000	Employ the contractor
	2.2 Asphalt Seal-Coating	km.	310,000	Employ the contractor
	2.3 Asphalt Overlay	km.	1,180,000	Employ the contractor
3.	Rehabilitation			
	3.1 Crushed Stone Surface	km.	350,000	Employ the contractor
	3.2 Cape Seal Surface	km.	1,100,000	Employ the contractor
	3.3 Asphalt Surface	km.	1,600,000	Employ the contractor
	3.4 Concrete Surface	km.	3,500,000	Employ the contractor
4.	Rehabilitation and Overlay	km.	2,300,000	Employ the contractor

Source: Department of Rural Roads

2.5 Pavement In-Place Recycling Technique

When pavement is distress more than repairing by normal maintenance, it has to use rehabilitation methods to increase the strength of pavement structure. In present, many rehabilitation projects in Thailand has still used remove surface, base, replace with new base and then overlay method. This technique has to do in plant and has to use original method as same as new road construction. Although this method can be done, the steps of operation are quite difficult especially in high traffic condition. In addition, the method is inefficient because it does not use any existing materials in the field. Another favorite method for rehabilitation projects in Thailand is thick asphalt overlay by paving new hot-mixed asphaltic concrete over existing pavement. This method increases thickness of original pavement, decrease overhead clearance under the bridge or over the tunnel, decrease shoulder width, etc. The original pavement rehabilitation methods are waste of budgets and new materials.

In last decade, there are demand for saving the budgets coincide with environment preservation by finding the rehabilitation methods that can uses the existing pavement in the field instead of opening a new quarry to produce new aggregate and transports its to the site. Therefore, the pavement rehabilitation has been a trend towards reusing the materials in the existing pavement as much as possible. One rehabilitation technique that has been used in many countries is pavement in-place recycling. This technique has been developed into high-tech equipments and machines and has also many relevant researches. Pavement in-place recycling has many benefits and advantages comparing with the conventional methods for example reduced time in operation, reduced costs of construction, conservation of aggregate and binders, preservation of existing pavement geometrics, preservation of the environment, less traffic disruption, and less user delay, etc.

2.5.1 Pavement Recycling

Somkiat (1984) said that pavement in-place recycling is not a new technique but it has been used for a long time in pavement rehabilitation. Charles Naville, Edward L. Lombard and Fritz S. Rostler has named for the originally reusing old asphaltic concrete in the existing pavement. The first publishing in pavement recycling was in Warren Brother's portable asphalt plant sales brochure in 1915. In the past, Pavement recycling was not acceptable due to high costs and asphalt production was generally plentiful and readily available at reasonable prices. In recent year, the fuel cost for transport has raised the price of manufactured aggregate to unacceptable levels. Similarly, the cost of asphalt has climbed up every year. Therefore, recycling of old asphaltic concrete in the existing pavement is now increasingly attractive to relevant engineers and agencies again. Therefore, there are many agencies -- American Association of State Highway and Transportation Officials (AASHTO), The National Cooperative Highway Research Program (NCHRP), Federal Highway Administration (FHWA), Corps of Engineers, Navy, Asphalt Reclaiming and Recycling Association (ARRA), The Asphalt Institute, National Asphalt Pavement Association, and Portland Cement Association -- have researched and developed into equipments, machines, stabilizing agents, admixture design etc.

2.5.2 In-Place Recycling

The recycling process is performed "in-place" has been done for a long time by common road construction machines such as backhoe, roller, etc. to break up and/or pulverize the existing asphalt pavement in-place at the depth more than 1 inch (2.5 cm.) and then the reclaimed asphalt pavement (RAP) material is modified by the addition of a variety of stabilizing agents: lime, Portland cement, foamed asphalt, etc. to build new pavement structure. (Epps, J.A., 1980 refered from Somkiat, 1984)

2.5.3 Cold-Mix Recycling

The first use of cold-mix recycling was in during 1940–1949. By using bitumen and Portland cement mixed with RAP materials that was cut by normal equipment and added new aggregate to improve the quality of pavement. The benefits of this method are no need to use heat during mixed materials process, so it can save energy and no pollution. The process for cold-mix recycling starts from keeping the sample of existing pavement to test and design the quantity of stabilizing agents such as lime, Portland cement, foamed asphalt, etc. Then breaking up and/or pulverizing the existing asphalt pavement not more than 1.5 inches in size. After that, taking RAP materials mix with stabilizing agents and new aggregate from mixing design. Finally, Bringing modified RAP materials back in place and compact to a specified density. (Vladis Servas, 1981 refered from Somkiat, 1984)

2.5.4 Cold In-Place Recycling or Pavement In-Place Recycling

In 1970s, there was shortage in asphalt cement, (AC) due to oil crisis making asphalt prices increased. Therefore, many research in pavement rehabilitation focused on reusing the old existing pavement. Since that time one technique that has been developed is cold in-place recycling or pavement in-place recycling.

Cold in-place recycling involves planning, crushing the existing asphalt pavement, rejuvenating the existing asphalt with cement, placing the material back down to a specified thickness, and compacting. This process is performed in-place, so there is no need to load and transport a majority of the material. (Bernard, 1984)

The first cold in-place recycling project found in the literature review was constructed in 1952. This project was a United States Navy airfield located in California" (Finn, 1980)

Pavement Recycling Guidelines for State and Local Governments (1997) explained the steps in cold in-place recycling that consist of preparation of construction area, milling the existing pavement, addition of stabilizing agents and virgin materials, laydown, compaction, and placement of surface course respectively.

PCA (1976) told that Portland cement is a well stabilizing agent that can be used with old existing pavement in the surface and base courses due to its high compressive strength.

ARRA (1991) explained Cold in-place recycling that can be performed in 2 ways as following:

1. Partial-depth reclaimation (Thin layer recycling): A portion of the bound layer (asphaltic concrete), normally between 75–100 mm. is used to produce a base course for generally low-to-medium traffic volume highways.

2. Full-depth reclaimation (Deep layer recycling): Both bound layer (asphaltic concrete) and portions of unbound (subbase, base) layers are crushed, mixed with binder, and placed as a stabilized base course. The recycling depth is between 100–300 mm.

2.5.5 Materials Used in Pavement In-Place Recycling

Theerachat, senior consult engineer of DOH, explained materials used in pavement in-place recycling to construct recycling treated base that consist of:

1. Reclaimed Asphalt Pavement, (RAP)

RAP materials may be surface treatment or asphaltic concrete that has been used for a long time with thickness 1–10 cm. Base course should be crushed stone base at lease 15 cm. All materials will be broke up and/or pulverized by cold-milling machine and mixed to be homogeneous materials (recycled materials).

2. Portland Cement

Portland cement type I is used in recycling work. The cement can be spread as a powder and inject water during mixing process, or as cement slurry inject directly into mixing chamber to build cement treated base.

3. Foamed Asphalt

Foam asphalt is produced by asphalt cement (AC) that heat up to 180°C in liquid condition. AC and water are injected via hoses under high pressure. AC spray and water spray are mixed together to become foamed asphalt. Foam asphalt can be directly used with recycled materials to build asphalt treated base, or used with cement slurry to build cement and asphalt treated base.

2.5.6 Machines Used in Pavement In-Place Recycling

Pavement in-place recycling process needs to use specific machines for breaking up and/or pulverizing the existing pavement to required depth. RAP material will be mixed with stabilizing agents in chamber of recycling machine and laydown modified material by paver to be new treated base and compacts with vibrating roller. The machines used in pavement in-place recycling process can be separated into 2 parts that consists of cold-milling machine with mix and paver as shown in Figures 2.2 and 2.3 or can uses only single machine that is cold recycler as shown in Figure 2.4.

1. Cold-Milling Machine

The machine use for crushing the existing pavement by milling process to take RAP material is cold-milling machine. The machine has cutting tools for milling the existing pavement that has asphaltic concrete thickness more than 12.5 cm. and move to breaking up and/or pulverizing chamber. RAP material will be placed on conveyor and moved to mix and paver.

2. Mix and Paver

RAP material from milling process will be sent to mix and paver. In mixing chamber, RAP materials and stabilizing agent such as lime, Portland cement, and foamed asphalt will be mixed together and then laydown to be new treated base.

3. Cold Recycler

In present, the leading recycling machine manufacturer, e.g. Wirtgen from Germany and CMI Terex from USA have built single recycling machine that can mill and mix in one unit. So, the machine is convenience, easy to operate, time saving, and high performance.

Wirtgen Cold Recycling Manual (2004) explained steps in recycling process that consist of preparation of construction area, milling the existing pavement, addition of stabilizing agent and virgin materials, laydown, compaction, and placement of surface course. The heart of machine is a milling/mixing drum equipped with a large number of special cutting tools as shown in Figure 2.5.

The drum rotates upwards and pulverizes the material in the existing pavement. While the machine moves forward with the drum rotating, water from a tanker coupled to the recycler is delivered through a flexible hose and is sprayed into the recycler's mixing chamber. Fluid stabilizing agents like Portland cement/water slurry or bitumen emulsion, either individually or in combination can also be introduced directly into the mixing chamber in a similar manner.

Figure 2.2 Cold-milling machine

Figure 2.3 Mix and paver machines

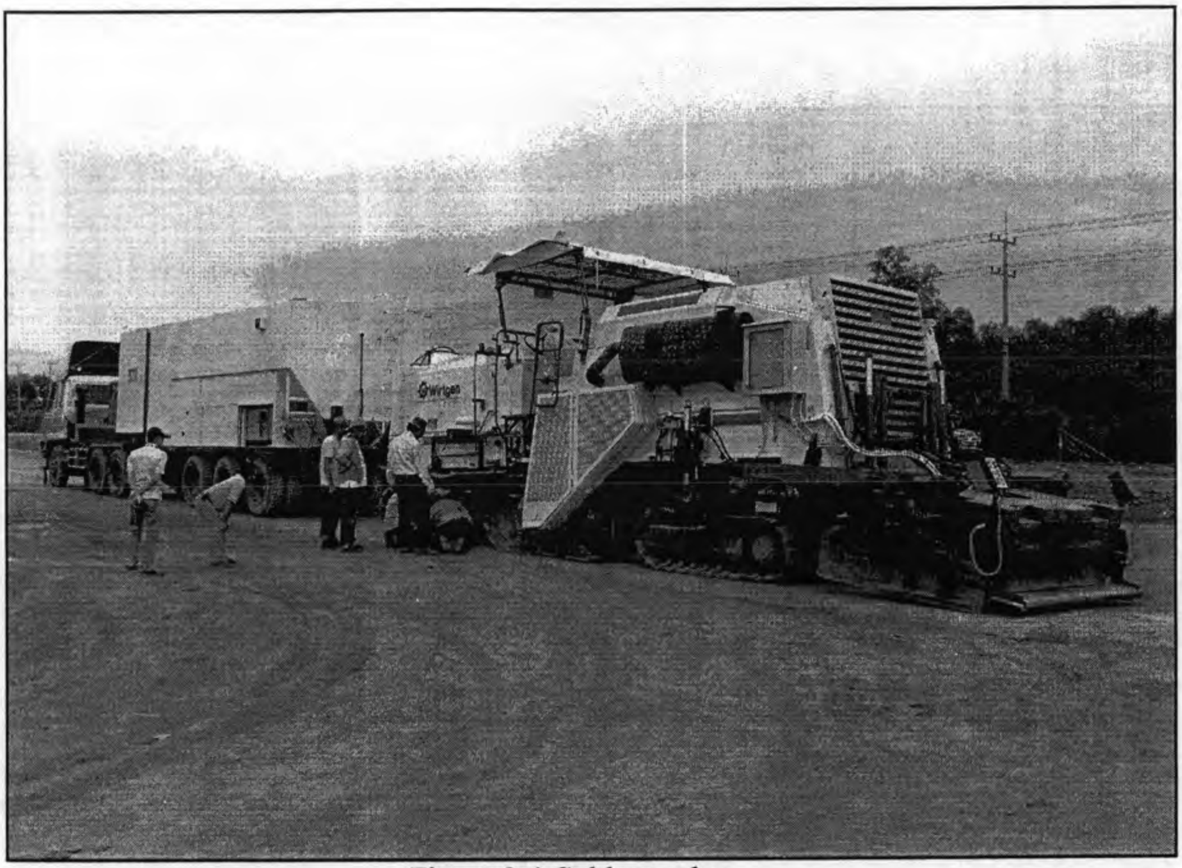
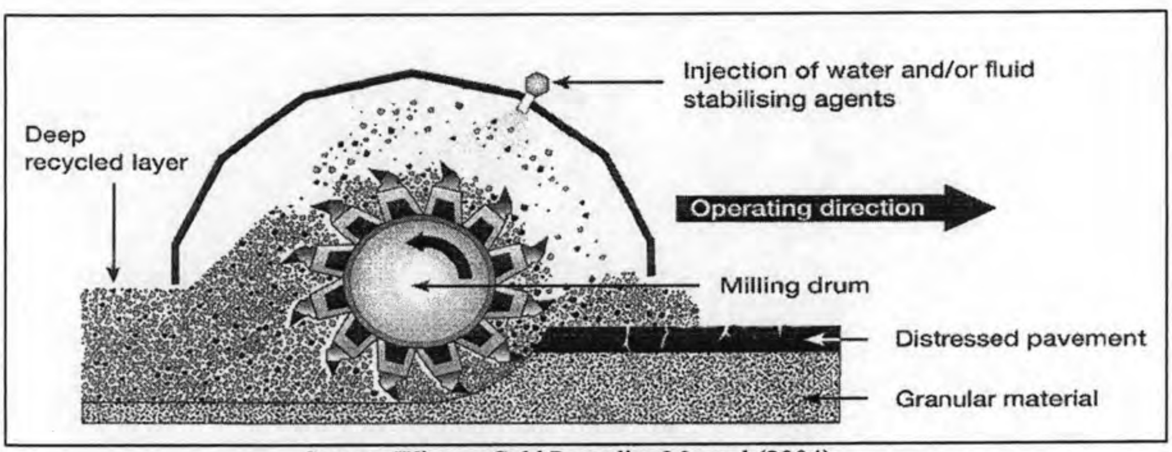


Figure 2.4 Cold recycler



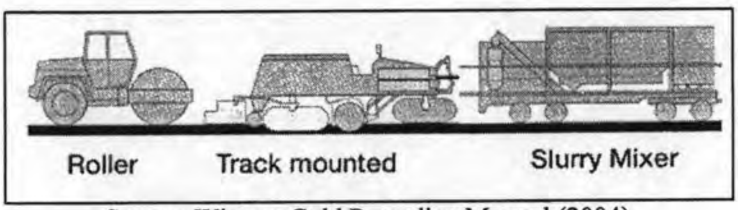
Source: Wirtgen Cold Recycling Manual (2004)

Figure 2.5 Rotation of milling drum

Recycling trains may be configured differently, depending upon the recycling application and the type of stabilizing agent that is used. In each case the recycling machine acts as the locomotive, and either pushes or pulls the equipment that is coupled to it, by means of pushbars or drawbars. Typical recycling trains are illustrated in Figures 2.6.

The recycling train as shown in Figure 2.6 is used when the recycled material is stabilized with cement slurry. The required application rate of both cement and water is accurately metered prior to being mixed together to form a slurry that is then pumped to the recycler via a flexible hose and injected into the milling chamber. Alternatively, the cement may be spread on the existing road surface as a powder ahead of the recycler and a water tanker substituted for the slurry mixer.

The material exiting the recycler receives initial compaction from a heavy vibrating roller to achieve uniform density throughout the recycled material. This material is then profiled with a motor grader before being finally compacted using both vibratory and pneumatic-tired rollers.



Source: Wirtgen Cold Recycling Manual (2004)

Figure 2.6 Track mount of cold recycler

4. Roller

After modified RAP materials is placed on pavement. Vibrating roller with weight at least 17.5 tons follow by tire roller with weight 12 tons are used in compaction process to reach the required density as shown in Figure 2.8.

Figure 2.7 Paving modified RAP materials

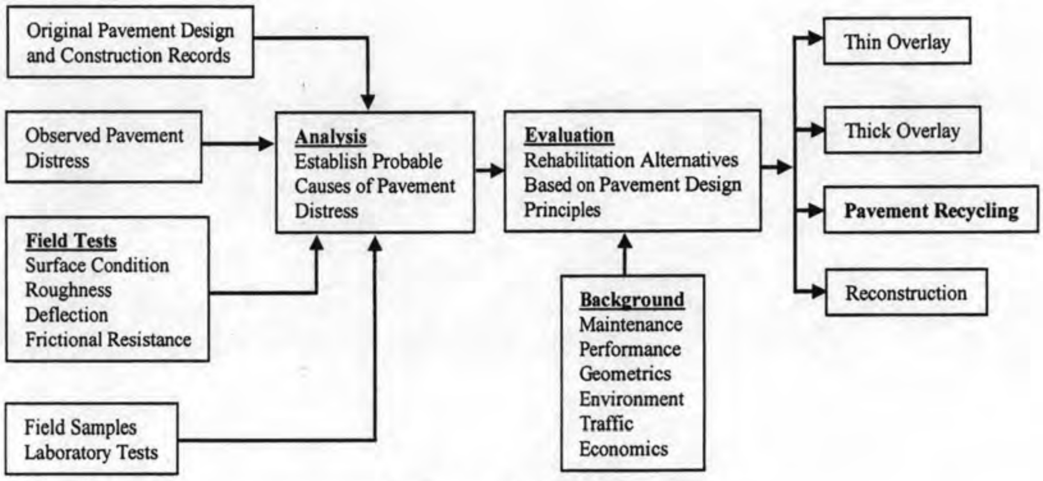
Figure 2.8 Vibrating roller and tire roller

2.6 Selecting Pavement In-Place Recycling for Pavement Rehabilitation

There are many researches and institutions describe the guideline for selecting pavement in-place recycling as a rehabilitation method. It can collect the interesting issues as following:

2.6.1 Guidelines for Selecting Pavement In-Place Recycling Method

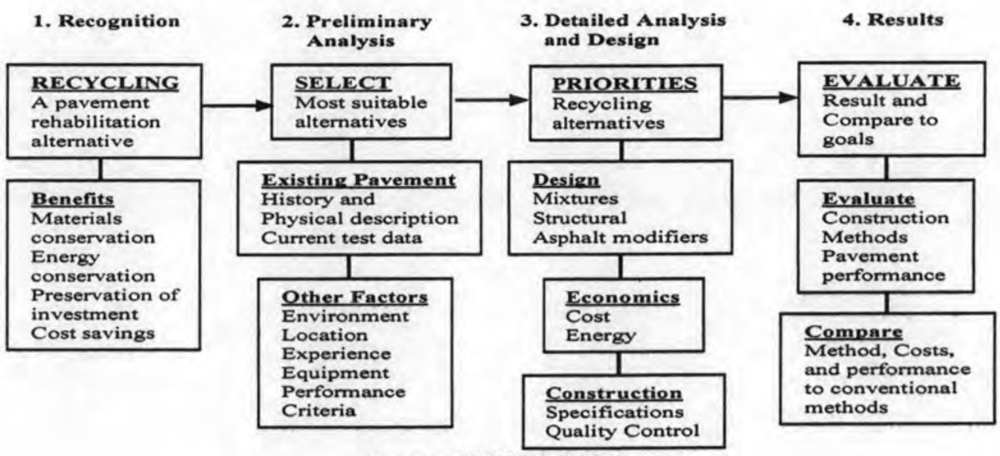
AASHTO (1993) established a guideline for selecting rehabilitation methods as shown in Figure 2.9 that depends on following:



Source: AASHTO (1993)

Figure 2.9 Guideline for selecting pavement rehabilitation methods

NCHRP (2001) defined a guideline for selecting Pavement recycling as a rehabilitation method in 4 steps as shown in Figure 2.10.



Source: NCHRP (2001)

Figure 2.10 Guideline for selecting pavement in-place recycling

2.6.2 Advantages and Benefits of Selecting Pavement In-Place Recycling

ARRA (1991) described one benefit of selecting pavement in-place recycling is a decrease in energy that is required to rehabilitate the road. The existing asphalt is used with the addition of stabilizing agents. There is no heating involved in the construction process. Another, the process is performed "in-place" eliminating the added expenditure of transportation of materials. The other benefits of recycling can be summarized as follows: reduced costs of construction, conservation of aggregate and binders, conservation of energy, preservation of the existing pavement geometrics, preservation of the environment, and less user delay, etc.

Bureau of Maintenance and Traffic Safety DOR (2007) explained the advantages and benefits of pavement in-place recycling as following:

1. Recycling the existing pavement by modified with stabilizing agents

2. No disposal, no toxic, preservation of the environment, preservation of resources

3. Less time to operate, time savings, reduce steps in process, fast open traffic after finish the work in each day

4. Reduced dust during construction

5. Fewer machines, decreased transport costs, not make other road damage from materials transport.

6. Homogeneous products, high weight capacity more than crushed stone base 20 cm.

Bureau of Administrative Maintenance DOH (2007) explained the advantages and benefits of pavement in-place recycling, as following:

1. Increasing the strength of pavement by mixing cement/asphalt in the existing pavement to make cement treated base/asphalt treated base that has high strength and capacity to support traffic load more than crushed stone base.

2. Increasing service life by reduced stress and strain in pavement structure more than crushed stone base, so the life of recycling road is longer than the crushed stone base road.

3. Keeping balance of road and shoulder reduced the thickness of new course over old pavement, so no need to expand shoulder and can keep the existing pavement geometrics.

4. Easy to rehabilitate in the future pavement distress especially rutting occurred less than crushed stone base, so it's easy to overlay in the future.

5. Savings in surfacing and shoulder works when rehabilitate full road width, the shoulder will smooth and strength.

6. Reduces effect on road users and community because fast operation and fewer machines can reduce noise and dust during construction.

7. Cost savings, the cost of works is cheaper than remove surface, base, replace with new base method.

8. Reduced damage of nearby roadways because the contractors always use overload trucks to transport materials.

9. Preservation of the environment and resources by recycling the existing materials.

2.6.3 Basic Criteria for Selecting Pavement In-Place Recycling

Bureau of Administrative Maintenance DOH (2007) defined criteria for selecting pavement in-place recycling as following:

1. Roadways in urban that have problems deal with leveling of road affecting nearby building.

2. Roadways in urban that have constraint level such as footpath, bridge, tunnel, etc.

3. Roadways have damages at surfacing and base.

4. Roadways consist of surfacing, base and subbase that have thickness following standard.

5. Roadways have suitable structure to build recycle base. Surfacing is 1 – 10 cm. and base is 15 – 20 cm.

6. Roadways that when overlay has to expand roadbed by benching or cut back slope.

7. Roadways is over soft clay that has stabilized problems of roadbed if overlay

8. Roadways have severe damages more than repair by overlay method such as rutting. There is high deflection over than to support all the life service. There are many cracking over than to patch

9. Roadways that the existing pavement cans recycling

10. Roadways are in the place that lack of raw materials. It has to deliver from far area and the price is expensive to unacceptable levels.

11. Roadways are in the conservation of environment area.

12. Roadways that overlay costs is higher than pavement in-place recycling

2.6.4 Comparison the Differences between Pavement In-Place Recycling and Conventional Method

DOH compared difference in operational process and difference in machines and waste in process between pavement in-place recycling and remove surface, base, replace with new base and then overlay as shown in Tables 2.3 and 2.4 respectively.

1. Difference in operational process

Table 2.3 Comparison the difference of operational process between pavement in-place recycling and the conventional method

Conventional method	Pavement in-place recycling
1. Construction time about 8 - 10 months for 200,000 m^2	1. Construction time about 3 - 4 months for 200,000 m^2
2. Remove all surface, base and take out	2. Recycling existing pavement
3. Long closed Traffic all construction time, Long time to operate, High user delay	3. Finished in one step, Short closed traffic, Short time to operate
4. Use new crushed stone not less than 15 – 20 cm. to add the strength of pavement structure, so making high surfacing	4. Use all existing pavement modified by stabilizing agents or add some aggregate as need to improve the pavement structure
5. Waste natural resources	5. Conservation of aggregate and binders for new roads
6. Make pollution to environment	6. No pollution because reuse materials
7. Use more trucks and machines, Waste of fuel	7. Use less machines, convenience and quick
8. No add cement in the base	8. Add cement in the base, so its strength is higher
9. Destroy roads during materials delivery, Risk to fatal accident	9. High capacity, Long life road, Reduced maintenance cost

Source: DOH, Highways Society of Thailand (2546:198)

It can find from Table 2.3 that pavement in-place recycling has many benefits more than conventional method in case of operational process for example use all existing material, no waste material, conservation of aggregate, decrease construction time, short closed traffic, short time to operate, high capacity pavement structure, and reduced long-term maintenance costs, etc.

2. Difference in machines and waste in process

Table 2.4 Comparison the difference of machines and waste in process between pavement in-place recycling and the conventional method

Process	Conventional method	Pavement in-place recycling
1. Excavator	Use	No use
2. Recycling machines	No use	Use
3. Trucks (to remove materials)	Use (high waste)	No use
4. Embankment	Use (environment problems)	Less use (depends on work)
5. Trucks (to deliver materials)	Use (high cost)	Some
6. Grader	Use	Some
7. Roller	More use	Less use
8. Operating time	More time	Less time
9. Traffic	High user delay	Less user delay
10. Fuel consumption	More	Less
11. Loss economics	More	Less

Source: DOH, Highways Society of Thailand (2546:201)

It can find from Table 2.3 that pavement in-place recycling has many benefits more than conventional method in case of machines and waste in process for example less use materials and machines, less time to operate, less fuel consumption, and less costs than conventional method.

2.7 Energy consumption and Costs in Pavement In-Place Recycling

The important issue having to consider for selecting pavement in-place recycling besides benefits and advantages is the costs. There are many researches, official agencies, and machine manufacturers have studied energy consumption and costs of pavement in-place recycling. It can conclude interesting topics as following:

2.7.1 Energy Consumption in Pavement In-Place Recycling

Bureau of Maintenance and Traffic Safety DOR (2007) compared the types and numbers of the machines using in pavement in-place recycling comparing with remove surface, base, replace with new base method as shown in Figures 2.11 and 2.12. It can see from the figures that numbers of machines that used in conventional methods are much more than in pavement in-place recycling. Therefore, the energy consumption in conventional methods is higher than pavement in-place recycling.

Figure 2.11 Machines used in conventional methods

Source: Bureau of Maintenance and Traffic Safety Department of Rural Roads (2007)

Figure 2.12 Machines used in pavement in-place recycling

However, ARRA (1991) said that the efficient and energy consumption of the machines in pavement in-place recycling are different in each project which depends on: local conditions, climate and traffic, type of technique and quality of materials used, and quality of the workmanship.

2.7.1 Costs in Pavement In-Place Recycling

Bureau of Administrative Maintenance DOH studied the costs comparison of pavement rehabilitation between pavement in-place recycling and remove surface, base, replace with new base method by considering the distance from quarry to the site in cases 100 km. as shown in Table 2.5. It can see that total costs of conventional method that are 132.40 Baht/m^2 is higher than total costs of pavement in-place recycling that are 100.00 Baht/m^2.

Table 2.5 Comparison costs of rehabilitation between pavement in-place recycling and the conventional method in case a quarry has distance 100 km. from the site

No.	List of Cost	Conventional Alternative (Baht/m^2)	Pavement in-place recycling (Baht/m^2)
1.	Remove surface and base	15.00	None
2.	Compact subgrade	1.00	None
3.	Supply of crushed stone 20 cm. The price at quarry 135 Baht/m^3 (loose) To dense = 135.00×1.5÷5 Baht/m^3	40.50	None
4.	The transport costs 100 km. 140 Baht/m^3 (loose) To dense using 5 m^2 = 140.00×1.5÷5 Baht/m^3	42.00	None
5.	Machines for construct new base	10.00	None
6.	Cold Recycler	None	40.00
7.	Mix and Paver	None	12.00
8.	Cement type I 3%	None	30.00
Total Cost of Work		108.50	82.00
The Administrative Costs, Interest, Profit, and VAT 22%		23.90	18.00
Total Costs		132.40	100.00

Source: DOH, Highways Society of Thailand (2546)

Table 2.5 shows that choosing pavement in-place recycling to be pavement rehabilitation method can save costs more than using the conventional method. The difference in costs comes from remove surface and base costs, compact subgrade costs, supply of crushed stone costs, transport costs, machines for construct new base costs

Pavement in-place recycling can use all existing pavement, so there is no costs in remove surface and base, compact subgrade, supply of crushed stone, transporting new aggregate, and machines for construct new base. The costs of pavement in-place recycling have only cold recycler, mix and paver, and Portland cement. Therefore, pavement in-place recycling can saves budgets more than conventional method.

Bureau of Maintenance and Traffic Safety DOR (2007) showed the costs in pavement structure improvement part that pavement in-place recycling has costs lower than conventional method 25% as shown in Table 2.6.

Table 2.6 Costs comparison between pavement in-place recycling and conventional method

Item	Conventional alternative	Pavement In-Place Recycling	Differentiate (%)
1. Pavement structure	6,896,449	5,118,877	1,777,572 (25%)
2. Surfacing	8,821,351	8,821,351	-
3. Traffic line and marking	852,480	852,480	-
Total	16,570,280	14,792,708	1,777,572 (25%)

Source: Bureau of Maintenance and Traffic Safety Department of Rural Roads (2007)

The results of cost comparison in studies as mentioned above is only estimated example. It can not apply this data for others new projects because factors affecting costs of pavement in-place recycling in each projects are quite different. Servas Vladis (1981) referred from Somkiat (1984) said that factors affecting costs of pavement in-place recycling comprised of the prices of new aggregate and stabilizing agents, the distance of materials delivery to the site, the competition of contractors for a job, recycling techniques, and the amount and size of the future projects.

Pavement Recycling Guidelines for State and Local Governments (1997) told the reported costs of pavement in-place recycling that varies from approximately $1.71/m2 to $9.87/m2 depending upon many factors such as depth of recycling, equipment type, and thickness of overlay. The reported savings of using pavement in-place recycling in stead of conventional alternative methods showed the initial savings have varied from 6 to 67 percent.

ARRA (1991) told that pavement in-place recycling is a cost savings method. The cause of cost savings for example low mobilization costs, reduced hauling costs for materials except liquid additives, high production and equipment can recycle up to 500 tons per hour, use of thin overlay or a chip seal for a surface course, reuse of all existing materials, and engineering costs are much lower when compared to other types of rehabilitation.

An economic improvement with pavement in-place recycling is the decreased cost. Several documents said these savings in different titles as follows: The economics of cold mix recycling suggest that a savings of 25–30% can be realized when compared to normal alternatives for pavement rehabilitation (Santucci & Hayashida, AASHTO, & Epps). Cold in-place recycling reuses the existing pavement structure and results in a stable road at a total energy savings of 40–50% less than conventional construction methods (ARRA, 1991). Cost savings encountered have ranged from 10–30% (USACE, 1992). High production rates combined with reuse of existing materials translates into cost significantly less than HMA overlay (Hicks, Rogge, 1995).

2.8 Chapter Conclusion

It can find from literature review that several documents interested in studying the energy consumption and costs in pavement in-place recycling. They described the benefits from using pavement in-place recycling instead of conventional method such as energy savings, cost savings, reduced costs, and cost effective. However, the costs in each pavement in-place recycling projects is quite different which depends on many involved factors. These past researches showed only rough data telling that choosing pavement in-place recycling in stead of conventional methods can decreased the costs in pavement rehabilitation. They didn't explain costs of pavement in-place that came from what factors. These data can not use to consider for the new projects especially in Thailand that the highway agencies DOH & DOR don't do it by self, but employing the contractors to operate.

Because DOH & DOR use a formula that comes from many factors for estimating direct costs of pavement in-place recycling which defining as direct costs of the contractor, and the amount of money that is calculated from Factor F defining as indirect costs of the contractor, making a problem that how difference between total costs estimation of DOH & DOR, and total costs estimation of the contractor is. To answer this question, it needs to understand costs structure in total costs of DOH & DOR, and costs structure in total costs of the contractor that consists of what factors and how these factors affecting the total costs. Consequently, it needs to have more study in factors affecting total costs of DOH & DOR, and factors affecting total costs & profit of the contractor in pavement in-place recycling projects which will be described in next chapter.