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DEDICATION

I dedicate this work to my beloved parents/
family and
Dr. Muhammad Bilal Khurshid

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First of all, I am grateful to *ALMIGHTY ALLAH*, who gave me strength to complete my research work successfully.

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Last but certainly not the least; I want to say thanks to my friends and classmates for their moral support and courage throughout this period.

Jamal

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LIST OF ABBREVIATIONS

IRI	The International Roughness Index
PSI	The Present Service ability Index or PSI
FHWA	Federal Highway Administration
WSDOT	Washington state department of transportation
AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
FWO	Frontier Works Organization
FWD	Falling Weight Deflectometer
HMA	Hot Mix Asphalt
NHA	National Highway Authority
QA	Quality Assurance
QC	Quality Control
DOT	Department of Transportation
JMF	Job Mix Formula
M2	Motorway (Islamabad – Lahore Section)
AC	Asphalt Concrete
SHRP	Strategic Highway Research Program
USACE	United States Army Corps of Engineers
PTR	Pneumatic Tyre Roller
ANOVA	Analysis of Variance
NCHRP	National Cooperative Highway Research Program

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ABSTRACT

It is usually considered that Quality control consists of a review, after an activity is completed. In actual, it is many individuals performing many appropriate activities at the right time. It is an approach and realization that something good should be achieved throughout the process. Quality requires all activities in conformance with valid requirements, no matter how large or small is their overall contribution to the whole project.

Quality is assessed by the performance, stability and appearance of a structure over a period of time. Basic purpose of the quality management is to ensure that the given requirements are met during execution and these could also be validated through various tests, trials, procedures and experienced judgment. There are several factors affecting the quality of a road project e.g. Excellent design good engineer practices, material, weather, equipment, and professional competency etcetera. All these factors are equally important but if working hands / executing agency does not perform the task with professional honesty and competency then use of best plan, ideal weather conditions and possession of state of the art machinery/equipment will be of no significance.

Transport in Pakistan is one of the rapidly growing sectors. It accounts for 12 % of GDP. In transport and communications sector annual growth is 2%. Its employment share is of 2.93 Million people or 6.4 % of the labor force. Restoration / preservation of the road network conditions to an acceptable level requires estimated annual expenditures of over 10 billion PKR. Land transport expected to stay for 100s of years for movement of people, goods and services. Highway mobility is critical to quality of life, wellbeing, economic progress, social welfare, national defense, domestic security and emergency preparedness. In Pakistan approximately 260,000 kilometers roads have been constructed. Apparently, it sounds good that there is no dearth of road network in our motherland but when it comes about the quality of the roads the situation becomes precarious. Importance of good execution during rehabilitation of the pavements and paucity of relevant resources necessitates the research work on quality. Formulation of a checklist / manual for upcoming transportation engineers is another subsequent aspect of this research work.

At international level some studies for maintenance of low volume roads and labor based rehabilitation have already been carried out. Some material on pavement performance exists but that is on basis of roughness etcetera. At national level NHA specifications -1998 provides some guidance in this regard. Method statement are being used in recent projects of national level.

Absence of research work of significant level and increasing requirement of users and agency necessitates some input for assurance of quality in execution which should be equally useful for better quality of work and safe/ prolonged service life of the road.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Quality is acknowledged to be a key issue for the reason that clients increasingly demand quality certification (Chung 2007). Time, cost and quality are commonly known as 'Iron Triangle' (Atkinson 1999). In fact, quality is end result that provides value to all.

Highway quality is all about achieving the shared goal of building, preserving and maintaining better roadways. Quality encompasses everything i.e. planning, design, workmanship and durability of the finished product. Transportation engineers see the quality in design, construction standards and long term performance. While, user sees quality in congestion relief, mobility and safety. Limited budgets, aging transportation system and increasing percentage of the infrastructure in need of significant repair are uphill tasks for highway / transportation Engineers. Therefore, a strong focus on quality is more important than ever before.

An attention to quality in all aspects of a highway project is important for a good final product that safely and efficiently meets the long term needs. With the increased demands on today's highway agencies, continuous quality improvements are essential for a successful highway program. On the other hand early deterioration of pavements particularly flexible ones is common feature in our country. Many reasons can be attributed towards this premature failure ranging from poor designing of roads to malpractices in the use of quality of materials. Out of many causes, we have selected to highlight the malicious effects of lack of good engineering practices in execution, non adherence to the given specifications, lack of supervision and professional dishonesty. The paper defines the specifications as well as execution methodology to be followed.

1.2 RESEARCH SIGNIFICANCE

After the construction of motorways, the road network in Pakistan has witnessed remarkable uplift in standards. Various parameters directly and indirectly contribute to the pavement quality performance. This research review the factors that contribute to the quality of pavement performance in Pakistan. This review was achieved via both literature review and questionnaire. Execution related factors include milling, crack repair, patch work, transportation and laying/compaction of asphalt. The consideration

and improvement of these factors in future pavement rehabilitation will lead to better pavement performance, longer service life and lower maintenance cost. Identification of the factors that contribute towards better quality will lead to a better understanding of pavement quality and thus improved performance, longer service life and lower maintenance costs.

1.3 PROBLEM STATEMENT

Mode of transportation generally depends upon attributes like travel time, speed , efficiency, cost , convenience and safety . Basing on these attributes the only system reliable effective and efficient for common people in Pakistan is road transport (Hussain 2014). Major transportation sub systems are land , air and water. 90% of the freight traffic and 92% of the passenger traffic is through road network (Ahmed 2013). This much significance of road network necessitates proper maintenance and rehabilitation of the roads. Florida DOT ensures that 100% of the acceptable maintenance standard on the State Highway System is achieved . While Srilanka is also maintaining the National Highway Network at an acceptable condition. National Highway Council of Pakistan lays down the national policies and guideline to be followed by NHA in the performance of Highway Asset functions (Irfan 2014). There are several factors effecting the quality of a road project e.g. engineer practices, material, weather, equipment and professional competency etcetera. All these factors are equally important but if working hands / executing agency does not perform the task with professional honesty and competency then use of best plan, ideal weather conditions and possession of state of the art machinery will be of no use. At international level some studies for maintenance of low volume roads and labour based rehabilitation have already been carried out. Some material on pavement performance exists but that is on basis of roughness etc. At national level NHA specifications - 1998 provides some guidance in this regard. Method statements are being used in recent projects of national level. Absence of research work of significant level and increasing requirement of users and agency necessitates some input for assurance of quality in execution which should be equally useful for better quality of work and safe and prolonged service life of the roads. Importance of good execution during rehabilitation of the pavements and paucity of relevant material necessitates the research work on quality improvement during execution of the project. In this process various factors effecting the quality will be analyzed as per their significance. NHA specifications

(Sampak 1998) was published in 1998, after 1998, a lot of changes have been witnessed in equipment, material and in execution methodology. Rehabilitation activities are routine matter in the field of transportation and pavements but rehabilitation of M2 became an important mile stone in history of rehabilitation in Pakistan. It was a golden opportunity to learn the new techniques of rehabilitation. First time milling strategy was used to such a mass level otherwise before this normally pulverization, kneading, compaction and laying of new asphaltic layer were the common practices. While, interviewing Brigadier Ayub on M2 project he openly expressed that before rehabilitation of M2 we used to look towards china. After rehabilitation of M2 now people consult Pakistan for rehabilitation techniques and strategies. Therefore, recent rehabilitation of M-2 will be discussed in details in this paper. Restoration / preservation of the road network conditions to an acceptable level requires estimated annual expenditures of over 10 billion PKR. Land transport expected to stay for 100s of years for movement of people, goods and services. Highway mobility is critical to quality of life, wellbeing, economic progress, social welfare, national defense, domestic security and emergency preparedness. In Pakistan approximately 260,000 kilometers roads have been constructed. Apparently, it sounds good that there is no dearth of road network in our motherland but when it comes about the quality of the roads the situation becomes precarious. Importance of good execution during rehabilitation of the pavements and paucity of relevant resources necessitates the research work on quality. Formulation of a check list / manual for upcoming transportation engineers is another subsequent aspect of this research work.

1.4 OBJECTIVES

After going through the literature review and research significance, following objectives were identified for analysis of factors and sub factors affecting the quality in execution of pavement rehabilitation.

a. To synthesize the factors and sub factors affecting the quality in pavement rehabilitation.
b. To analyse and accord the priority to the factors and sub factors affecting the quality in pavement rehabilitation.
c. To formulate a checklist and guidelines for quality assurance during execution of the pavement rehabilitation.

1.5 SCOPE AND LIMITATIONS

Literature review on previous research findings was carried out. Scope of the research was to identify and prioritize the factors and sub factors to ensure quality in execution of pavements rehabilitation. Area of study was Islamabad – Lahore motorway (M-2). Since in rehabilitation of M-2 main emphasis was on laying of overlay after milling. Therefore, While calculating the factors and sub factors, only surface courses were considered and for thesis purposes, following were assumed:-

a. Machineries and equipment is available in well maintained condition. It is being certified by the competent authorities at regular intervals. Hence, machinery equipment is in ideal working condition.
b. Base and sub-base layers does not have structural / functional feature.
c. Shoulders don't need rehabilitation.
d. Since it is rehabilitation work so there is no issue/concern regarding survey and geometrics of the road.
e. There is no issue of availability of manpower. However, competency/experience of the labour is variable.
f. All material is of good quality. Ancillary works are excluded from the study.
g. Drawings / design and JMF have been approved by the consultants.
h. Relevant tests / inspections are being performed regularly so there are not discussed in the study.
i. Transportation/ storage facilities and practices for raw materials are ideal.
j. All safety requirements are known and are adhered to.
k. Weather conditions and working hours are in accordance with the working environment.

1.6 RESEARCH METHODOLOGY

Execution of rehabilitation of M2 was considered as test case of massive rehabilitation of pavement in Pakistan. The execution plan was to distribute the rehabilitation in three sectors. 1st segment was from Lahore to Pindi Bhatian, 2nd was from Pindi Bhatian to Kallar Kahar and 3rd was from Kallar Kahar to Islamabad. As per initial plan each sector was required to be equipped with couple of asphalt plants and Paver Groups. First ever milling was done and state of the art machinery was used.

These characteristics were the inspirations to bring the methodology of execution at national level. Execution methodology of each and every stage was witnessed in detail and focus was kept on execution of milling followed by HMA laying. Site visits were made, project managers, supervisory staff and field staff was interacted and their input was a great help in formulating a questionnaire. Academia was also contributing in directing my research work towards logical conclusions. After that engineering students, common public, NHA and other setups of FWO which were not directly involved in rehabilitation of FWO were also contacted. After collection of data it was sifted, analyzed and converted to some useful material for transportation / highway engineers and executing agencies.

1.7 ORGANIZATION OF THESIS

Chapter 1 is about the background, introduction, problem statement and objectives. While, in Chapter 2 literature review is covered. Chapter 3 is primarily the research methodology. In Chapter 4 analysis and results are discussed. Finally, the research work is concluded along with certain recommendations in chapter 7.

1.8 SUMMARY

In this chapter quality and its importance in rehabilitation of pavement have been introduced. This chapter also gave the significance of the study, its objectives, scope and limitations. Basis of the study was to formulate some guidelines for young Transportation / Highway Engineers.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The literature review describes the theoretical justification for the development of questionnaire and check list. No details regarding the methods for assessing the quality of execution was found except certain laboratory /field tests or guaranty/warranty restrictions but those were not true reflection of quality. Therefore, M2 was taken as case study and all the procedures involved in the execution were examined and the activities were observed in overall scenario. Then the factors considered important for a comprehensive quality in execution are discussed. In this context National Highway Authority General Specification -1998 , Quality Management Hand Book for M2 and asphalt pavement construction by Khalid Hassan Siddiqui were consulted. Formation of each rehabilitation strategy alternative should address the improvement necessitated for structural, functional and drainage along with additional repair technique (Kathleen T. Hall 2001).

2.2 LITERATURE SUMMARY

2.2.1 NHA Specification

As per NHA specifications section - III, (Sampak 1998) activities included in rehabilitation of surface courses and pavements are asphaltic material, bituminous prime coat, bituminous tack coat, BST and seal coat, wearing course, shoulder treatment, Bit mac, hot recycling and cold milling.

2.2.2 Quality Management Hand Book for M2

It was compiled by Mujaddad Afzal. He describes that important activities for good quality execution in rehabilitation of pavement includes selection and storage of materials, asphalt plant and its operations, vehicle inspection, transportation , laying and compaction of HMA, milling of asphalt pavement, finishing / road furniture, final testing prior to open roadway , selection and storage of materials, asphalt plant and its operations, vehicle inspection, transportation , laying and compaction of HMA, milling of asphalt pavement, finishing / road furniture, final testing prior to open roadway.

2.2.3 Asphalt Pavement Construction

In “Asphalt Pavement Construction” Mr. Khalid Hassan Siddiqui described about the factors affecting compaction of asphalt hot mix , included the effects of material properties and asphaltic course thickness, mix temperature and weather

condition. In addition to aforesaid factors, check lists for asphalt batching plant were discussed by him. He numerated the check lists for material handling/storage, cold feed, asphalt heating, circulating and temperature of mixture, drum mix plant, batch plant, dryer/drum collector, sampling/testing, records and miscellaneous responsibilities.

2.2.4 Hot Mix Asphalt Materials

"Hot Mix Asphalt Materials, Mixture Design and Construction "(2nd edition) (L.Roberts 1991) recommends the tests for aggregate gradation, asphalt content, temperature, mixture properties of laboratory samples, theoretical maximum density, in place density, smoothness, visual inspections and field management of volumetric properties for quality control /assurance.

2.2.5 Rehabilitation Studies

Asphalt Pavement Rehabilitation Treatments (Kathleen T. Hall 2001) briefly describes the necessity and utility of full-depth or partial-depth repair, patching, cold milling , hot in-place recycling, cold in-place recycling, asphalt overlay and concrete overlay. Rehabilitation studies for highway pavement indicates geometric restrictions, construction duration, environmental impact , conservation of natural resources , agency's experience with the use of the rehabilitation techniques involved, traffic safety during construction, worker safety during construction, contractor's experience with the rehabilitation techniques involved, availability of needed equipment and materials, competition among providers of materials, stimulation of local industry and political concerns are the factors which influence the selection. The elements of pavement condition rating are type of defect, severity of the defect and extent to which the road surface is affected by the defect (DOT 2010).

2.3 THEORATICAL ASPECTS OF REHABILITATION AND MAINTENANCE

A pavement might be considered to have reached the end of its design life when it reaches a poor level of service ability, distress, or when cost of maintenance be comes too high. Therefore, factors considered important for evaluations are surface condition, present serviceability index (PSI), maintenance activities and costs, geometrics, federal functional classification, traffic information, rehabilitation costs, life cycle costs, age since initial construction, age since last major rehabilitation, pavement design , accident record information, program scheduling and cost data, friction data, and deflection data for resurfacing evaluation.

2.3.1 Evaluation of the Condition

It forms the basis for evaluating pavement performance. Evaluation of the condition is a fundamental aspect of pavement maintenance. Assessing the pavement condition begins with collecting data. Collection and analysis of pavement condition data forms the foundation of an effective pavement management system. Pavement surface is viewed and evaluation is made to determine the type of distress, severity of distress and extent of distress. Moreover, Distress type, severity, and extent help to get full picture of damage on pavement surfaces and in determination of appropriate category, type and timing of remedial action for the pavement. Four characteristics of pavement condition that can be used to evaluate the pavement quality are pavement roughness (ride ability), pavement distress (surface condition), pavement deflection (structural failure) and skid resistance (safety). The IRI scale versus the ride quality is shown in Table 2.1.

Table2.1: FHWA pavement roughness versus ride quality

Condition Term	IRI	Ride Quality
Very Good	<0.95m/km	Acceptable 0–2.68m/km
Good	0.95–1.49m/km	
Fair	1.50–1.88m/km	
Poor	1.89–2.68m/km	
Very Poor	>2.68m/km	Unacceptable

2.3.2 Pavement Condition Survey

Pavement performance is the efficacy to serve traffic over a given period of time. Surface condition of a pavement is generally described by structural and functional distresses. The structural distresses may include cracking caused by permanent or plastic deformation in the wheel-path caused by repetitive loads, environmental and material related cracks caused by thermal stresses and aging of the asphalt binder. Functional condition describes the pavement surface roughness related to the ride quality expressed commonly in terms of International Roughness Index (IRI), Rutting and PCR indices etcetera. Deflection is the source of structural cracking, Rutting, Thermal & Index cracking are source of functional failure.

2.3.3 IRI, Rutting and Cracking Indices Measurements

IRI is a standardized index of longitudinal unevenness and can be described as a total appraisal of the unevenness that affects drivers. The IRI is a continuation of the "in/mi" roughness statistic in use since the automobile was developed. The IRI summarizes the roughness qualities that impact vehicle response, and is most appropriate when a roughness measure is desired that relates to overall vehicle operating cost, overall ride quality, dynamic wheel loads, and overall surface condition. To know about the decision of rehabilitation data was obtained from different sources like NHA, FWO and Zeeruk International (Pvt.) Ltd. A heap of data was obtained which was then collated and sifted for the useful material. Greenwood profilometer was used for M-2 project. It is the latest inertial profiler. The data created by the profilometer was analyzed through the software provided by the manufacturer.

2.3.4 Deflection Tests

FWD tests were carried out to determine the structural capacity of the pavement. Each lane was tested separately in which lane 1 was truck lane, lane 2 was middle lane and lane 3 was inner most lane for both south and north bounds. The testing was carried out from Thokar Niaz Baig to Islamabad toll plaza and vice versa for each lane of South bound and North bound respectively. FWD was used to estimate pavement structural capacity for overlay design and overloading. Data received was in pdf format. Chainage was carried out for every 100 meter. Values of maximum IRI and Rutting were calculated at 100 meter interval but deflection was noted at interval of 200 meter and for each interval of 200 meter 3 readings were noted and maximum value among all three i.e. of heaviest load was used.

2.3.5 Typical Ranges of Service life for Different Rehabilitations

Performance of a given rehabilitation strategy is very difficult to predict (Kathleen T. Hall 2001). Rehabilitation performance is particularly sensitive to the appropriateness of use of the technique for the type of distress present, and for the point in the structural life of the pavement at which the rehabilitation is applied, construction quality of pre-overlay repairs, materials used and quality of the rehabilitation. He also described the typical ranges of service lives for overlays. These ranges are tabulated in Table 2.2

Table 2.2: Typical ranges of service lives for rehabilitation treatments

Treatment	Typical range of service life, years
Reconstruction:	
Reconstruction in asphalt	15 – 25
Reconstruction in concrete	20 – 30
Asphalt pavement rehabilitation:	
Structural asphalt overlay of asphalt pavement	8 – 15
Structural concrete overlay of asphalt pavement	20 – 30
Surface recycling without overlay	4 – 8
Non structural asphalt overlay of asphalt pavement	4 – 8
Nonstructural (ultrathin) concrete overlay of asphalt pavement	5 – 15
Asphalt patching without overlay	4 – 8
Concrete pavement rehabilitation:	
Structural asphalt overlay of concrete pavement	8 – 15
Asphalt or concrete overlay of fractured concrete slab	15 – 25
Unbounded concrete overlay of concrete pavement	20 – 30
Non structural asphalt overlay of concrete pavement	4 – 8
Bonded concrete overlay of concrete pavement	15 – 25
Restoration without overlay	5 –15
Asphalt-overlaid concrete pavement rehabilitation*:*	
Structural asphalt overlay of AC/PCC pavement	8 – 15
Asphalt or concrete overlay of fractured concrete slab	15 – 25
Unbounded concrete overlay of AC/PCC pavement	20 – 30
Surface recycling without overlay	4 – 8
Nonstructural asphalt overlay of AC/PCC pavement	4
Nonstructural (ultrathin) concrete overlay of AC/PCC pavement	5 – 15

2.3.6 Rehabilitation Planning

As per NHA specification (Sampak 1998) activities involved in new construction , rehabilitation and maintenance are tabulated in Table 2.3

Table 2.3: Activities involved for rejuvenating of pavements

Description	New construction	Rehabilitation	Maintenance
Bituminous prime coat	Yes	Yes	Yes
Bituminous tack coat	Yes	Yes	Yes
Bituminous surface treatment	Yes	Yes	Yes
Seal coat	Yes	Yes	Yes
Asphaltic concrete wearing course	Yes	Yes	No
Plant mix	Yes	Yes	No
Shoulder treatment	Yes	Yes	Yes
Bit-Mac	No	Yes	Yes
Hot recycling of asphalt	No	Yes	No
Cold milling	No	Yes	Yes
Concrete pavements	Yes	Yes	Yes

2.4 IMPORTANT ACTIVITIES INVOLVED IN REHABILITATION

2.4.1 Milling

2.4.1.1 Milling Machines

Milling machines are the primary method for removing existing surface material of pavement prior to overlay (L.Roberts 1991). They can be fitted with automatic grade control to restore both longitudinal and transverse grade can remove most existing pavement distortions such as rutting, bumps and deteriorated surface material.

2.4.1.2 Surface area

Milling also produces a rough, grooved surface, which will increase the existing pavement surface area when compared to an un-grooved surface. The surface area increase is dependent on the type, number, condition and spacing of cutting drum teeth but is typically in the range of 20 to 30 percent. It requires a corresponding increase in tack coat when compared to an un-milled surface ((TRB) 2000). Depending upon type of machine and pavement condition, its production rate is 100-200 tons/ hr

(for larger machines). However, this additional surface are along with an increase in aggregate interlock promotes improved bonding characteristics.

2.4.1.3 Cold Milling

It is effective at removing distresses in the top of the pavement, providing a smoother surface by removing vertical deformations and improving surface frication (DOT 2010). Cold milling machines can cut asphalt pavement surface to controlled depths. In the process, the pavement is reduced to the desired maximum particle size. Particle size is dependent upon the depth of the cut and the forward speed of the cold milling equipment. After the asphalt-treated layers have been removed, the remaining aggregate to be incorporated in the recycled hot-mix is scarified and removed with loaders, grade trimmers on other conventional equipment. Cold milling machines can cut asphalt pavement surface to controlled depths (Siddiqui 1993) . In the process, the pavement is reduced to the desired maximum particle size. It is dependent upon the depth of the cut and the forward speed of the cold milling equipment. Surface preparation is vital to provide the best opportunity to achieve a high bond strength (FHWA Apr 2016). The goal of surface preparation is to produce a clean and dry surface. On existing pavements, milling is encouraged for its many benefits. First, milling removes the uppermost materials which are typically the most compromised by traffic wear and weathering. Second, milling helps to smooth out any irregularities in grade that may have developed within the pavement. Third, milling improves the bonding characteristics of the overlay to the existing pavement. The negative aspects of milling are the cost associated with milling and the added cleaning typically connected to milling as it can produce excess fine material which may be difficult to eliminate by sweeping or other forms of removal.

2.4.1.4 NHA specifications

According to NHA specifications (Sampak 1998) milling drum shall be capable of level and grade adjustments and it shall have variable speed provision to ensure production of smooth or rough milled surface. Level and grade control shall be ensured through electronic sensors, capable of giving an accuracy of **+/- 2 mm.** Scraper bars and belt conveyor system shall ensure picking and loading of milled material in a truck. Milled surface shall be cleaned by wire brushes or compressed air for subsequent operation.

2.4.1.5 Good Quality Milled Surface

Maximum size of broken material reduces to basic size of aggregates. Asphaltic material lumps shall be reduced to a maximum size of fifteen mm (Sampak 1998).. Cold milling and inlay is the process of removing all or part of an HMA overlay and placing a new HMA overlay (Bureau 2014). Frequently, distresses will appear in the wheel path of the pavement, or along a joint, and not in the rest of the lane. Where this occurs, it is possible to remove the HMA overlay on one half of the lane, patch the under lying pavement, and then place a new HMA overlay, or mill out the affected joint and place an HMA inlay. Sometimes a new surface course is then placed over the entire pavement to complete the rehabilitation.

2.4.1.6 Post Milling Operation

After milling, pavement surface should be cleaned off by sweeping before any overlay is placed otherwise debris such as dirt and dust may decrease bonding between the new overlay and the existing pavement (Mujaddad Afzal 2014). When sweeping, more than one pass is typically needed to remove all the debris, continue sweeping until all debris is removed.

2.4.2 Crack repair / Patch work

2.4.2.1 Repair Methods

Existing pavement crack repair methods depend upon the type / severity of cracks. Badly cracked pavement sections must be patched or replaced because these distresses are often symptoms of more extensive pavement or subgrade structural failure ((TRB) 2000). Existing cracks other than those symptomatic of structural failure should be cleaned out and filled with a crack sealing material when the cracks are clean and dry.

2.4.2.2 Working and Non-Working Cracks

Cracks with significant annual horizontal movement ("working" cracks) should have a crack sealing treatment. e.g., cracks that are more than 1⁄8″ in the summer and significantly larger in the winter. Crack filling is generally performed on cracks that do not open and close due to environmental conditions. They have little annual horizontal movement ("non- working" cracks). In general, a patch is less than a typical rehabilitation in size and scope. They are less than full roadway width and/or are less than project length (DOT)

2.4.2.3 FHWA Crack Treatment Program

It emphasizes on determination of type of maintenance for the cracked pavement based on the density and condition of cracks and suggests remedial measure accordingly e.g. A pavement surface treatment is appropriate for a pavement with high density of cracks that have moderate to no crack edge deterioration. A crack treatment is proper for a pavement with moderate density of cracks that have moderate to no crack edge deterioration. A crack repair is necessary for pavements with moderate density of cracks that have a high level of crack edge deterioration. FHWA also emphasizes on selection of materials and procedures for the crack treatment operation based on environmental, equipment, personnel, and cost-effectiveness considerations followed by periodical evaluation of treatment performance. Construction practices, contractor experience and workmanship are powerful contributors to the success of micro surfacing. This also applies to other preservation treatments used for asphalt pavements. Construction practices also greatly affect the performance of joint sealants with the two most significant factors that cause premature failure being the omission of sandblasting (cleaning of the joint) during placement and in adequate sealant recess (sealant overflow exposing the sealant to tire traffic).

2.4.2.4 Primary Considerations

Factors required to be addressed when planning crack-sealing or crack-filling operations are climatic conditions, highway classification, traffic level/ percent trucks, crack characteristics /density, materials, material placement configurations, procedures / equipment and safety. Recommended criteria for determining the crack sealing / filling decision in Manuals of Practice by HSRP-H-348 is shown in Table 2.4 (Kelly L. Smith 1994). Generally crack sealing is typically performed in cold weather climates and crack filling in warm weather climates.

Table 2.4 : Recommended criteria for determining whether to seal or fill

Crack	Crack Treatment Activity	
Width, in'	Crack Sealing 0.2 to 0.75	Crack Filling 0.2 to 1.0
Edge Deterioration	Minimal to none	Moderate to none
Annual Horizontal Movement (in)	0.2 - 0.1	< 0.1
Type of Crack	Transverse thermal cracks	Longitudinal reflective cracks
	Transverse reflective cracks	Longitudinal cold-joint cracks
	Longitudinal reflective cracks	Longitudinal edge cracks
	Longitudinal cold-joint cracks	Distantly spaced block cracks

2.4.2.5 Preparation for Crack Sealing/Filling

In order for the sealant to bond the crack must be clean and dry Compressed air is commonly used to clean the crack (Decker 2014). Routing of cracks is generally performed on transverse cracks that are "working" and greater than 3mm ($1/8''$)in width prior to crack sealing. Routing may be detrimental to pavement so over 6 years old due to aging of the mixture. As per pavement repair SHRP – H – 348 Crack sealing is a preventive maintenance activity Amid-winter evaluation is highly recommended as it will show treatment effectiveness during a time of near maximum pavement contraction and near maximum crack opening. As per crack repair NCHRP Report 784 Crack sealing and crack filling are widely used for preventive maintenance of asphalt pavements. However, successful crack sealing and crack filling applications continue to be perceived as an art. The time to complete crack treatments prior to surface treatment is recommended to be one season before the surface treatment. As per crack repair NCHRP – H – 784 Do rout when crack opening 3mm to 12mm, cracks 12mm to 20mm shall be evaluated to determine appropriateness and cracks greater than 19mm shall be cleaned and filled. Do not rout, when crack opening less than 3mm, fatigue cracks, pavements with high-density cracking and pavements being considered for rehabilitation.

2.4.2.6 Crack Cutting

The desired cutting depth and corresponding gauge setting should be established prior to formal cutting of cracks. Saw blade so router-bits must be checked for sharpness and sized or spaced to produce the desired cutting width (Decker 2014). A general rule is to cut only secondary cracks spaced farther than 12" from a primary crack. Secondary cracks closer than 12" (305 mm) should be cleaned and sealed only. Vertical-spindle router is perhaps the least damaging and most maneuverable cutting machine. However, its production rate is quite low (Kelly L. Smith 1994). Carbide router-bits are highly recommended over steel router-bits. The four primary procedures used in preparing crack channels are Air blasting, Hot air blasting, Sandblasting and Wire brushing.

2.4.2.7 Placing of material

As per crack repair NCHRP Report- 784 As Sealant and filler materials can be placed in cracks in numerous configurations. The application procedure for all crack treatment materials is basically the same, regardless of what application device is used. Pressure applicators are almost always used. However, pour-pots are occasionally used for applying cold-applied emulsion materials. In all cases, a relatively free-flowing material must be poured into and possibly over the crack channel. These placement configurations are grouped into four categories, Flush-fill, Reservoir, over band and combination (reservoir and over band). Sufficient amount of sand applied to fully cover emulsion material. Toilet paper, dust, or powder applied so as to fully cover hot-applied rubber-modified asphalts (Kelly L. Smith 1994).

a. Situations where crack sealing is not appropriate
    (1) Cracks are too wide, too deep or too numerous.
    (2) "Non-working" cracks (filler is cheaper and quicker)
    (3) Pavement deterioration too severe (fatigue or alligator cracking)
    (4) If major surface rehabilitation/repair is scheduled within the next two years (e.g. overlay, in place recycling, chip seal)
    (5) If sealing would cover more than 25% of surface area (diminishes pavements kid safety).

b. Situations where crack filling is not appropriate
    (1) "Working" cracks ($\frac{1}{8}$″movement per year).
    (2) Pavement deterioration too severe (fatigue cracking).

(3) If cold-in-place recycling (CIR)is scheduled in the near future).

(4) Ifreconstructionisscheduledwithin2–3years.

2.4.3 Summary of Crack Treatment

With cracking and further oxidation more hardening takes place and aggregates and asphalt are likely to loose bond between each other leading to quicker pavement deterioration and shorter pavement life (Siddiqui 1993).This is the reason that lesser asphalt is not safe and leads to poor performance of the road. On the other hand higher quantity of asphalt also creates problems of rutting in the pavements.

2.4.4 Brooming, cleaning and drying

Hot air blasting is performed with a hot compressed-air (HCA) lance, or heat lance, connected to a compressed-air unit (Kelly L. Smith 1994). Sand blasting is a labor-intensive operation that is quite effective at removing debris, laitance and loosened AC fragments from the sidewalls of sawn cracks. Dirt and debris are adequately blown from crack channel and surrounding pavement area to well off edge of roadway. When cleaning and drying with hot compressed air, intended bonding surfaces are partially darkened but not burned. Cleaning operation is maintained just ahead of sealing or filling operation to retain crack cleanliness. Hot-air blasting operation is conducted immediately ahead of hot-applied sealant or filler installation so that the potential for moisture condensation is minimized and crack surface warmth is maximized (150 feet maximum). Blasting operations (sand or air) always directed away from passing traffic. Air blasting and hot-air blasting nozzles are held not more than 2 inches away from crack channel during first pass. Sand blasting nozzle is directed against crack sidewalls and maintained 4 to 6 inches away. Any bituminous layer shall be kept clean and uncontaminated for so long as it remains uncovered by succeeding layers or surface treatment but when a bituminous layer is trafficked before the next layer is laid, it must be thoroughly cleaned off and a tack coat should be applied.

2.4.5 Significance of Prime Coat / Tack Coat and Application Methodology

2.4.5.1 Interface Preparation

If a pavement displayed no bonding within its layers, a 60% loss of life could be expected. Similarly, Brown and Brunton reported that no bonding would cause a 75% reduction in pavement life, and at 70% bond strength, a 70% reduction in pavement life could occur (FHWA Apr 2016). If adjacent layers do not bond to one

another they essentially behave as multiple independent thin layers situation for which none of them are designed to accommodate the anticipated traffic bending stresses .Inadequate bonding between layers can result in de-lamination (de- bonding) followed by longitudinal wheel path cracking, fatigue cracking, potholes, and other distresses such as rutting that greatly reduce pavement life. Prime coat can also be applied on a sub-base or on the top granular base layer, if necessary (Cristian 2006).

2.4.5.2 Application of Bitumen

The bitumen will be applied at a certain minimum temperature which depends on the grade of the bitumen. Asphaltic binder used shall conform to standard specification of petroleum asphalt having grades 60-70 or 80-100 penetration. Generally it will meet the requirement of AASHTO M-20. The length of the spread shall not exceed than that which truck loaded with cover coat material can immediately cover. The angle of spray nozzles and height of spray bars shall be adjusted and frequently checked in order to ensure uniform spray of bitumen. The spray of bitumen will be uniform. Quantity of the bitumen (cutback asphalt type mentioned above) to be sprayed will be 1.63 liter /sq.m (Sampak 1998). Prime coat shall be applied when the surface to be treated is dry, except that when emulsified asphalt is used, the surface may be reasonably moist (FHWA Apr 2016). Primed surface should be kept undisturbed for at least 24 hours, so that the bituminous material travels beneath and leaves the top surface in non-tacky condition. No asphaltic operations shall start on a tacky condition. Rate for application of asphaltic material (cut back / emulsified) are as per table 2.4.

Table 2.5: Rate for application of asphaltic material

Type of surface	**Litres per square meter**	
	Minimum	**Maximum**
Subgrade, sub base, water bound base courses and crushed stone base course	.65	1.75
Bridge , wearing surfaces and concrete pavement	.15	.4

The application is prohibited when the weather is foggy or rainy or when the atmospheric temperature is below 15 degree C. Prior to the application of prime coat all loose materials shall be removed from the surface and the same shall be cleaned by means of approved mechanical sweepers or blowers / hand brooms , until it is as free from dust as is deemed practicable. It is clear that the cost of a tack coat application is relatively insignificant but the cost of repairing a bond failure is very significant (FHWA Apr 2016).

2.4.5.3 Application of tack coat

As per tack coat technical brief (FHWA Apr 2016) tack coat is a sprayed application of an asphalt binder upon an existing asphalt or Portland cement concrete pavement prior to an overlay or between layers of new asphalt concrete. This thin membrane of asphalt binder provides the glue between the layers, creating a monolithic structure which performs as a unit as opposed to unbound, independent, layers. Materials used for tack coats are emulsified asphalt (most common) and performance grade asphalt. While cutbacks are still used, their usage is much less than other options.

a. Tack coat shall be applied on both horizontal and vertical milled surfaces (Sampak 1998).
b. According to project, construction and quality controlled by Botezatu Cristian (FHWA Apr 2016) usually prime coats are being executed on sub-base layer if they cannot be paved right away and consist in a sprayed application of a cutback or emulsion asphalt applied to the surface of untreated sub-base or base layers in order to fill the surface voids and protect the sub-base from weather, stabilize the fines and preserve the sub-base material and Promote bonding to the subsequent pavement layers.

2.4.5.4 Drainage

Typical moisture sources are rainwater, run off and high ground water. These sources are prevented from entering the pavement structure or accumulating in the subgrade through surface drainage and subsurface drainage (Cristian 2006). Usually, it is more cost effective and less risky to prevent moisture entry and accumulation using surface drainage than to effect moisture removal using subsurface drainage.

2.4.5.5 Impermeable HMA

HMA tends to be impermeable below about 8 percent air voids, therefore proper compaction practices should be followed to ensure an impermeable pavement. Also, minor cracks in the HMA should be promptly sealed.

2.4.5.6 Slope

The pavement section should be sloped to allow rain water to sheet flow quickly to the edge where it is typically collected in a curb and gutter system or a roadside ditch. A generally accepted standard is a 2 percent cross slope.

2.4.5.7 Grade

The curb and gutter or roadside ditch must be properly graded to allow flow to central collection points such as catch basins or detention ponds. A generally accepted standard is a grade of 0.5 percent or more although lesser grades have been used effectively.

2.4.5.8 Gravity Flow

Water from surrounding areas can be absorbed by the soil then flow by gravity to areas underneath the pavement structure. In pavement with high air voids (above 8 - 9 percent), water can percolate down through the pavement structure itself.

2.4.5.9 Capillary Rise

It is the rise in a liquid above the level of zero pressure due to a net upward force produced by the attraction of the water molecules to a solid surface. Capillary rise can be substantial and in general, the smaller the soil grain size, the greater the potential for capillary rise. Often, capillary rise is a problem in areas of high groundwater tables. If visual observations reveal a significant drainage deficiency, more intensive inspection may be conducted (Kathleen T. Hall 2001). The effectiveness of both longitudinal edge drains and day lighted bases may be evaluated by using a truck to dump water on the pavement and observing the outflow, or by observing the outflow during or immediately after a rainfall.

2.4.5.10 Surface Drainage

Surface drainage system is the most neglected part of our existing reconstruction / rehabilitation projects. Due to absence of this important aspect some of the road become flooded in rains. To avoid the surface water entrance, it is essential that a pavement surface should be free from holes and cracks (Siddiqui 1993). It should have a permanently tight joint with the shoulder and be shaped and sloped to control the adequate run off. Ditches are formed at the edge of paved surface to receive water from the surface. This water is carried to the lower ground a catch basins and storm

sewers. It is essential to maintain a tight joint between the shoulder and ditches or gutters which is really a problem. However it is necessary to prevent water which leaks through the joint. Slopes for highway pavements are needed to facilitate the flow of water from their surfaces. Therefore highways pavements are constructed with a crown or slope which allow the surface water to move across the shoulder into a ditch or gutter at the side.

2.4.6 Preparation and Transportation of HMA

2.4.6.1 Significance of Requisite Temperature

Where the existing surface is distorted, a levelling course of hot asphalt mix shall be required to restore proper cross-section prior to construction of the overlay (Sampak 1998). Construction requirements Asphalt cement shall be heated within a temperature range of hundred and thirty five to hundred and sixty three (135-163) degrees centigrade at the time of mixing. Asphalt cement heated above maximum shown shall be considered overheated and shall be rejected and removed from job site. (Sampak 1998). Temperature of asphalt, except for temporary fluctuations, shall not be lower than fifteen (15) degrees centigrade below the temperature of the aggregate, at the time, the two materials enter into the pug-mill. Each aggregate ingredient shall be heated and dried at temperature not to exceed hundred and sixty three (163) degrees centigrade. If aggregate contain sufficient moisture to cause foaming in the mixture or their temperature is in excess of hundred and sixty three (163) degrees centigrade, they shall be removed from the bins and returned to their respective stock piles. In no case, shall the temperature of asphaltic mix exceed 163 degree centigrade when discharged from the pug-mill. Immediately after heating, the aggregates shall be screened to required sizes and stored in separate hot bins for batching and mixing with bituminous material .Asphalt plant shall have minimum three and half (3 1/2) sieve decks to effectively control the gradation of hot bins.

2.4.6.2 Transportation Considerations

Bed of the dumper should be free of any debris or residual of previous supply and should be coated with any release agent to avoid adhesion of HMA with the bed (Mujaddad Afzal 2014). Fuel Oil and Kerosene are not allowed for this purpose. After the bed is coated, any excess release agent must be drained from the bed. Material should be loaded in three equal portions in the truck. Truck speed should be in the range of 60-70 km/hr to avoid cooling through air blows. The bed must also be of a size that

will fit into the hopper without pressing down on the paver. Trucks should minimize their distance travelled over freshly tacked pavement. After application of tack coat, the surface will not be used for movement of trucks. The tack coated surface will only be used in order to transfer material into the paver. The truck will not use the freshly laid pavement. HMA must be placed within 1 to 2 hours of its production. If the batching plant is far from site or weather condition is not friendly, tarpaulin must be used to avoid heat loss of HMA. Temperature of HMA while loading should be 155±5°C. while, unloading the bed of the truck should be raised slowly to avoid segregation. The truck bed should be partially raised and the load allowed to "break" before the tailgate is opened to prevent the mix from dribbling from the load into the paver hopper. This technique will help to minimize segregation that occurs between loads.

2.4.6.3 Visual Inspection of HMA

Inspections should be made when hauling truck arrives at site if any of the fault is noted the mix should not be laid and must be recycled (Mujaddad Afzal 2014). It must be checked for Blue Smoke, Stiff Appearance , Mix Slump in Truck, Lean or Dull Appearance , Contaminations, Bleeding because of release agent ,diesel fuel, and Segregation.

2.4.7 Paving Process of HMA

2.4.7.1 Machine vs Manual Paving

From the start it must be mentioned that all bituminous materials are machine laid, hand laid materials being restricted to small areas, usually only in areas where machines don’t have the possibility of access (Cristian 2006). The most critical feature of the paver is the self-leveling screed unit. It also provides initial mat compaction. For surface layer (wearing) the thickness is usually of 4cm after compaction.

2.4.7.2 Lift Properties

In order to avoid mat tearing or cracks a good thumb rule is that the depth of the compacted lift should be at least three times the nominal maximum aggregate size. Thickness should be checked frequently by means of gauge rod, at least two gauge rods must be provided while laying operation. Laid material should be of uniform thickness and texture segregation should not occur at any point.

2.4.7.3 Screed Unit

The most critical feature of the paver is the self-leveling screed unit, which determines the profile of the HMA being placed (Cristian 2006). The screed takes the

head of HMA from the material delivery system, strikes it off at the correct thickness and provides initial mat compaction. After paver description is easier to understand the hole paving process i.e. mixtures transportation by trucks from the asphalt plant (the mixtures are covered to not loose heat and for other consideration), the mixtures is loaded in the front of the paver, the paver is laying the mixtures, in the same time pushing the truck from the front, extra material is cleaned and lastly compaction.

2.4.7.4 Checking Of Mat Thickness Before Compaction

Before compaction mat temperature should be checked, Lower temperature will increase mat thickness and high temperature will decrease the mat thickness (Mujaddad Afzal 2014). Thickness of the mat should be checked with a Depth Gauge, Samples for laboratory testing will be taken after laying each 500 ton of the Hot Mix Asphalt. All mixed material may be delivered to the paver in time to permit completion of spreading, finishing and compaction of the mixture during daylight hours. All bituminous materials may be delivered to the paver at a temperature between 145^{o} C+5^{o} C. Mixtures delivered to the paver at low temperature may be discarded. Rolling should begin as soon as the mixture will bear the roller without undue displacement.

2.4.8 Operation of Paver Machine

The capacity of paver is 160 tons/hour and with 80% efficiency it comes out to be 128 tons/hour. The production rate of asphalt plant is 1000 tons/day so considering this quantity the maximum paving that can be done in one day is 1000 tons/day. Care will be taken to minimize the spillage of mix out of the hopper during operation or while unloading. Cut-off shoes or screed extensions shall be used to vary the paver width. After compaction, mat will be checked with straightedge for smoothness of the pavement. Core cutting will be carried out subsequently to know the thickness and compaction of pavement. Application of a thin HMA overlay is a viable option for improving ride ability and surface friction, reducing hydroplaning and tire splash (using an open graded friction course), and improving the profile, crown, and cross slope (DOT 2010).

2.4.8.1 Significance of Air void Ratio

In compacting HMA pavements James A Scherocman describes properly designed, a HMA mix should have an air-void content in the range of 3% to 5%. If the compacted mix has a high air-void content (greater than 8%), the mix will not perform as well under traffic. Similarly, if the compacted mix has a low air-void content (less than 3%), the mix will be susceptible to permanent deformation or rutting and also to

distortion under the applied traffic loads. The amount of permanent deformation or rutting that develops under load in a HMA material is also directly related to the air-void content of the mix. As the air-void content decreases, the amount of rutting that will occur in that mix also decreases. If, however, the air-void content of the mix is reduced to less than 3%, an increase in the rate of rutting of the mix can result. With time, the asphalt-cement binder in an asphalt-concrete mix will oxidize and become more brittle. This oxidation or aging process causes the asphalt cement to decrease in penetration and increase in viscosity. The rate of oxidation is directly related to the air-void content of the mix. The lower the air-void content, the less quickly the HMA material will age and become stiffer. An asphalt-concrete mix must be fully compacted before it cools to a temperature of about 175 F. At temperatures above this value, the mix is normally still warm enough for the compaction equipment to reorient the aggregate particles into their densest configuration. Below that temperature, however, the mix is generally too stiff to increase in density any significant amount with continued rolling, although roller marks can often be removed below this compaction cutoff temperature. The mix must, therefore, be compacted while it is still hot. Five factors directly affect the rate of cooling of the asphalt concrete mix when that material is placed on top of another existing layer of the pavement structure air temperature; base temperature; mix laydown temperature, layer thickness and wind velocity.

2.4.8.2 Asphaltic Course Thickness vis a vis compaction

In general it is easier to achieve required density in thick lifts of asphalt concrete (Siddiqui 1993). Thick lifts hold heat longer and so offer more time to compact. Rapid cooling of thin lifts makes it essential that complete the compaction process as rapidly as possible. As a consequences mix temperature generally should be higher for thin lifts, 2 inches compacted or less to allow enough time to complete the rolling operation. With thickener lifts, 3 inches compacted or greater, it is generally desirable to reduce the mix temperature somewhat. In thicker lifts, the lower temperature of the asphalt binder permits the sufficient viscosity to develop in the binder soon enough to hold the particles in position. In compacting HMA pavements JAMES A. SCHEROCMAN describes that probably the most important factor in the rate of cooling of an asphalt concrete mix is the thickness of the layer being placed and compacted. As the thickness of the layer increases, the time available for compaction also increases. It takes considerably longer for a 3-in. thick layer of HMA to cool to the cutoff temperature of 175 F than for a 1-in. layer to cool to the same temperature. The cooling time is not

directly proportional to the lift thickness but is geometrically proportional. For example on a 40 F day with the temperature of the base at the same value, a 3-in thick layer of HMA placed at a temperature of 250 F will take 19 minutes to cool from the laydown temperature to the cutoff temperature of 175 F. On the same 40 F day, with the same base temperature and for the same mix laydown temperature of 250 F, a 1-in. thick HMA layer will cool to the cutoff temperature in only 3 minutes. Lift properties In order to avoid mat tearing or cracks a good thumb rule is that the depth of the compacted lift should be at least three times the nominal maximum aggregate size. Laid material should be of uniform thickness and texture. Segregation should not occur at any point. Measures should be taken to correct the mat problems by working on the cause resulting imperfection.

2.4.8.3 Mix Temperature vis a vis compaction

Mix temperature is a principal factor affecting compaction. Good Compaction can only occur while the asphalt binder is fluid enough to act as a lubricant (Siddiqui 1993). When it cools enough to act as an adhesive, further rolling essentially becomes useless. The best time to roll an asphalt mixture is when its resistance to compaction is the least, while at the same time it is capable of supporting the roller without excessive shoving.

2.4.8.4 Operating Speed for Compaction

Rolling shall be accomplished with steel wheel rollers of a minimum weight of 10 tons (Sampak 1998). Rollers shall move at a uniform speed not to exceed 3 mph with the drive roll nearest the paver. The speed should not exceed 3 mph for steel-wheeled breakdown rollers or 5 mph for pneumatic-tired rollers (Mujaddad Afzal 2014). Rolling shall be continued until and roller marks are eliminated and the minimum density has been obtained. To prevent adhesion of the mixture to the rollers, it shall be necessary to keep the wheels properly moisture with water mixed with very small quantities of detergent or other approved material. The pavement shall be compacted to at least 94% of maximum theoretical density and at no more than 6% air voids.

2.5 COMPACTION OF HOT MIX ASPHALT

As soon as the material is spread by the paver, rolling may be started as early as possible, but shoulder be done with care to prevent unduly roughening the surface (Siddiqui 1993). Mix temperature is a principal factor affecting compaction. The initial

or breakdown pass with the roller is made as soon as it is possible to roll the mixture without cracking the mat or having the mix pick up on the roller wheels preferably at temperature 145+5^{o} C. The second or intermediate rolling follows the breaks-down rolling as closely as possible while the paving mix is still at a temperature that will result in maximum density (90^{o} C-100^{o} C). Finish rolling is done when the material is still workable enough to remove roller marks. Rolling will not be prolonged till cracks appear.

2.5.1 Speed of Paver and Rollers

The rollers may be operated at speed slow enough to avoid displacement of the bituminous mixture. The number and weight of rollers should be sufficient to compact the mixture to the required density. The use of equipment which results in excessive crushing of the aggregate will not be permitted. The bituminous mixture should be spread by an automatically controlled bituminous paver. The automatically controlled paver should spread the mixture without tearing the surface and may strike a finish that is smooth, true to cross section, uniform in density and texture and free from hollows, transverse corrugations and other irregularities. The paver should be operated at a speed which may give the best results and which coordinates satisfactorily with the rate of delivery of the mixture to the paver so as to provide a uniform rate of placement without intermittent operation of the paver. The motion of the roller should be at all times be slow enough to avoid displacement of the mixture. To prevent adhesion of the mixture to the rollers, the wheels of the rollers should be kept properly moistened with water but an excess of water will not be permitted. The initial or break down rolling should be followed by rolling with a pneumatic-tired roller. When the specified density is not obtained, changes in the size and /or number of rollers should be made as corrective measure to satisfy the density requirements. The line of rolling should not be suddenly changed or the direction of rolling suddenly reversed, thereby displacing the mix. If rolling causes material displacements, the affected areas are restored to their original grade with loose material before being re-rolled.

2.5.2 Sequence of Rolling

2.5.2.1 Initial / breakdown rolling

Initial or break down rolling will be done with steel drum tandem roller as soon as the mixture will bear the roller weight without undue displacement. In no case shall the temperature be less than hundred and twenty 120 ºC for initial break down rolling. Minimum Roller weight will be 10 tons. Roller shall move at uniform speed not

exceeding 5 km/hr with drive roll nearest the paver. To prevent adhesion of the mixture to the roller, roller wheels will be kept moist with water. In the next step, pneumatic tire roller (PTR) will be used for compaction. PTR will compact the pavement at the speed not exceeding 8 km/hr before the temperature drops down to 110 ºC. It shall be provided with paving screeds, however final compaction shall be carried out with conventional rolling equipment approved by the Engineer considering the type of material and thickness of recycled layer. Monitor density during the compaction process by the use of nuclear density gauges to assure that the minimum required compaction is being obtained (Sampak 1998). Pavement shall be compacted to 97% of the laboratory compaction. Rolling is usually continued until the pavement is compacted to the required density, or the temperature has dropped to a point where further compaction may produce negative results. However, final compaction shall be checked after completion of rolling as determined by AASHTO T-230 method and shall not be less than ninety seven (97) percent of the Marshall density. Unless otherwise directed, rolling shall begin at the lower side and proceed longitudinally, parallel to the road centerline, each trip overlapping one-half of the roller width, gradually progressing to the crown of the road. When paving in echelon or abutting a previously placed lane, the longitudinal joint should be rolled first followed by the regular rolling procedure. The first paver will pave the fast (inner lane) lane and will take the reference level from the existing asphalt surface at the inner shoulder edge (Mujaddad Afzal 2014). A cross slope of 2% will be fixed in the paver. The second paver will follow the first paver and Pave middle and slow (outer lane) lane by taking its reference level from freshly laid fast lane and adjust the cross slope of 2%. On super elevated curves the rolling shall begin at the low side and progress to the high side by overlapping of longitudinal trips parallel to the centerline. Steel-wheeled roller is normally used for breakdown rolling. Vibratory or static weight tandem rollers are usually preferred and mostly used for breakdown rolling successfully. To decide the weight of a roller for such rolling, temperature, thickness and stability of the mix are the major things to be considered. A roller weighing 8 to 12 tons is often used for such purpose. The best rolling pattern for the roller to be used may be worked out and followed to achieve uniform compaction across the line. Sharp turns and quick starts or stop must be avoided. The second movement of the roller should be to reverse in the same path until the roller reaches the previously compacted material. At this point it should swing over and move forward to the required patch. The forth movement is reversal in the third path and repetition of

the previous operation. After the entire width of the mix being placed has been covered in this fashion, the roller should swing across the spread to the low side and repeat the process. With this pattern the lap of the roller with succeeding passes need not be more than 75 mm to 100 mm. With steel wheeled rollers the operation should always progress with the drive wheel forward in the direction of paving. This is the most important in break down rolling. The greatest percentage of compaction occurs during a breakdown pass. The reason of breakdown rolling with the drive wheel is that there is a more direct vertical load applied by this wheel than the tiller wheel.

2.5.2.2 Intermediate Rolling

Second or intermediate rolling should follow breakdown rolling when the asphalt mix is still plastic and at a temperature that will result in maximum density. Pneumatic tired or vibratory tandem rollers may be used for intermediate rolling. Turning of pneumatic tired roller may be avoided unless undue displacement is stopped. Vibratory tandem rollers are used to provide required densities.

2.5.2.3 Finish rolling

It is done only for the improvement of the surface. The hot-mix spread may be repeatedly examined behind the paver to check whether the hot-mix has too much asphalt or too little asphalt or segregated aggregates. If bad material is observed, it should be immediately replaced with new good mix. After each spread, the surface may be checked with straight edge to see the smoothness of the surface. The degree or amount of compaction obtained by rolling is determined by density tests. A guideline for the paver operator should always be used. It should be parallel to the center line of the road. Marks from previous rolling must be eliminated. Rolling shall be continued until all roller marks are eliminated. Paving screeds should be designed to provide initial compaction and shaping the surface to give the required grade and profile. Continue rolling until the surface is of uniform texture, true to grade and cross section, and the required field density is obtained. Skin patching will not be allowed i.e. any mixture that becomes loose and broken, mixed with dirt, contains cracking, or is in any way defective shall be removed full depth, replaced with fresh hot mixture and immediately compacted to conform to the surrounding area. Rollers should be in good condition and capable of being reversed without backlash to compact the mixture should be used. Operate rollers with the drive wheels nearest the paver and at uniform speeds slow enough to avoid displacement of the mixture. Complete the compaction

prior to the mixture cooling below a workable temperature. Perform finish rolling to remove roller marks resulting from the compaction rolling operations.

2.6 EXECUTION OF JOINTS

All mixtures shall be spread at the temperature not less than 130 ºC. The longitudinal joint in one layer shall offset to that in the layer below, by approximately 15 cm. However the joint in the top layer shall be at the center line of the pavement marking (Sampak 1998). Production of mixture shall be maintained and paver will lay the HMA continuously to avoid transverse joint.

2.7 SUMMARY

Decision to go for rehabilitation activities is dependent on numerous factors. IRI, deflection, severity and intensity of the cracks are the technical factors while cost effectiveness, availability of funds climatic conditions and use of the roads also have their due importance in taking the decision of rehabilitation. In isolation best technique / activity can't fetch the best results. Rehabilitation strategy must be seen in holistic picture. A rehabilitation strategy normally is developed and targeted to address specified efficiencies with a particular pavement type (Bureau 2014). The strategy usually will be a combination of several rehabilitation techniques or methods that, when completed, will corrected in the most cost-effective manner. Khalid Hussain Siddique asks in asphalt pavement construction Why our huge amounts are lavishly spent and wasted on construction work and we cannot achieve the specified quality? Why the contracts are awarded on the lowest costs when the specified quality is difficult to achieve in such low billing rates? Why the contracts are awarded to such contractors having no construction experience and even they do not have batching plants, paving equipment's, lab equipment's and qualified personnel? These are the questions whose accurate and right answers can properly guide us to the right path. So it is essential for the contractor to look for the quality of work instead of quantity and to follow the project specification which is also the main demand of consultant.

RESEARCH METHODOLOGY

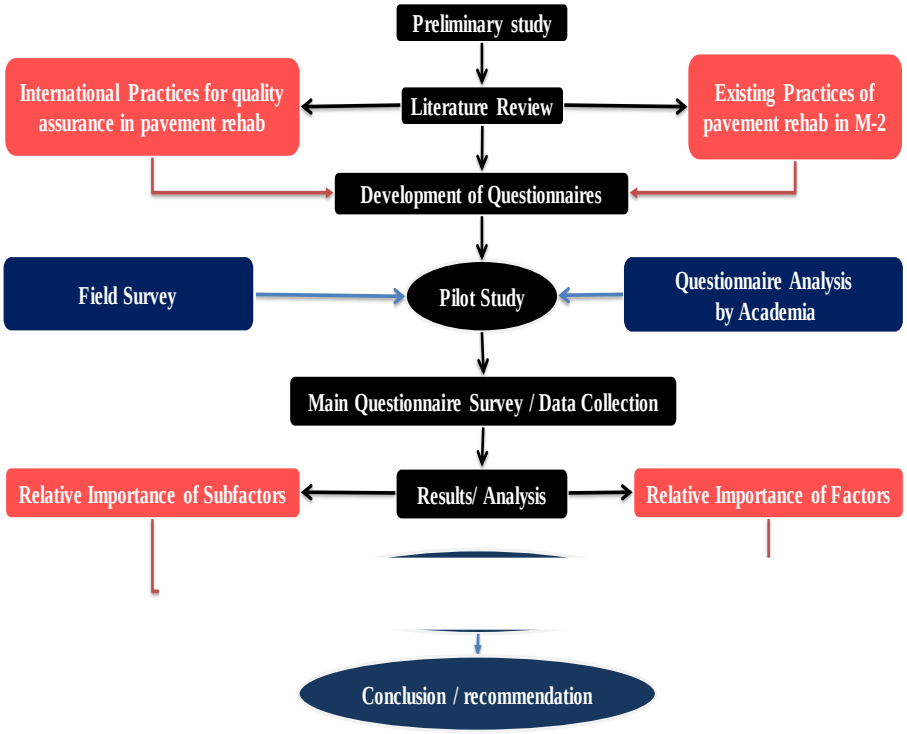


Figure 3.1 Research Methodologies

3.1 INTRODUCTION

To commence the research work preliminary study was carried out right after finalization of the topic. For preliminary study course work of Transportation Engineering and the persons already involved in rehabilitation work were consulted. In the first chapter desired objectives had been identified. Second chapter gave the detailed literature review to cover the objectives in different aspects and angles. It identified international practices, prior research in this field and situation in our country. Most of the material on internet and websites was related to reconstruction of pavements. Anyhow, after having better knowledge about the subject, this chapter will systematically explain the methods adopted for attainment of research objectives.

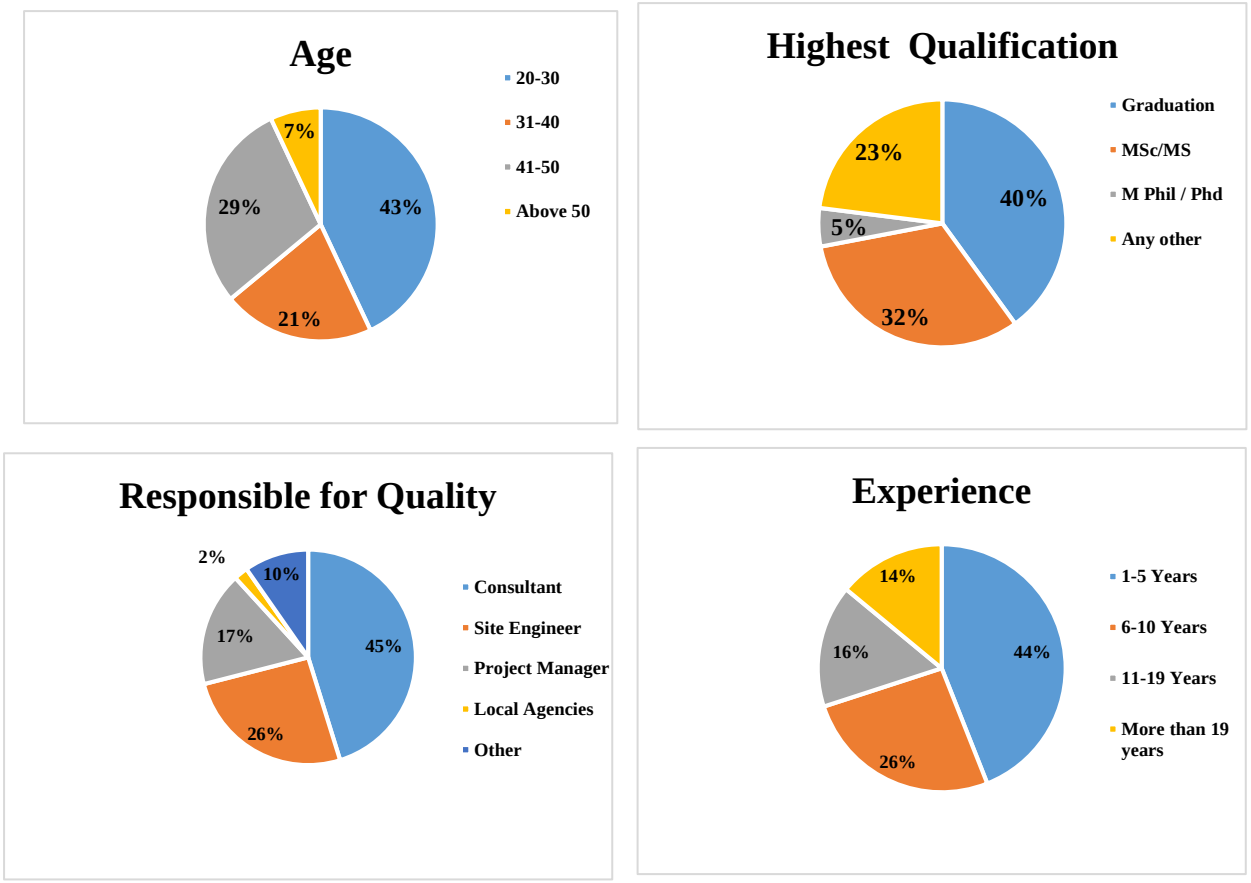


Figure 3.2 Respondent's Demographic Information

3.2 FIELD SURVEY

After the literature review first thing was quite clear that both quality and rehabilitation are vast subjects. Therefore, field visits and academic discussions were adopted to narrow down the scope of the research work. Endeavor was made to keep the progress and direction of the research work logical. Consultation of the literature review vis-a-vis execution methodology on ground was established in every activity. Some of the thumbs rules noted from the field staff for good quality of rehabilitation work e.g. greater paving thickness gives better riding quality, milling at slow speed means good milling. If there are 6-12 cracks in 25-50 sqm area these should be removed by small milling machine followed by paving, instead of repair / filling up of cracks. Narrow intact portion between two extension extensive cracked portions must be examined critically for potential threat of crack development. Problems of air void ratio, flakiness and excessive wastage may come even after following the job mix formula in true letter and spirit. Beside the maintenance of HMA temperature during

transportation, tarpaulin can also be used for maintenance of IRI value & safety of marking / cat eyes etcetera.

3.3 QUESTIONNAIRE SURVEY

To proceed logically in research work, it is important to understand the relationship between the desired result and the data collected. If it can be derived from collected data, must be established. In addition to above the selection of the method is also dependent on type of research being undertaken. What is the focus of the study and how much control is exercised over the variable. For studies where expert opinion is sought from a wide range of experts about the same factors on similar scale, then questionnaire surveys are considered the best approach. As in this case opinion of experts was required, therefore questionnaire survey was selected as the preferred method of data collection. This chapter explains the research technique adopted for completion of this study. Research strategy explains the methodology to accomplish research objectives.

3.4 DEVELOPMENT OF QUESTIONNAIRE

The importance of questionnaire design cannot be over stated in a questionnaire based survey, same has been highlighted in earlier researches. A properly designed survey should allow the respondents to answer with ease, be less time consuming and maintain their interest till the end. Several apparently insignificant factors influence the response rate, these include questionnaire length, dimensions, size of the paper used and how the questions are organized. In order to better understand the development of surveys, prior questionnaire based studies were identified and studied in detail. Without follow up the response rate will be very low (Dillman 2000). Follow up was carried out through phone, emails, whatsapp, text messages and post to ensure maximum response. Primary method of data collection remained interaction with executing agencies of the rehabilitation project of M2 along with questionnaire survey and interviews. An endeavor was made to know about the techniques for good execution in rehabilitation of pavements but no worthwhile material could be found for quality & rehabilitation. Therefore, guidelines were obtained from safety and reconstruction. Current methods for safety evaluation being used in the world were also studied to have some idea about questionnaire / check list for quality. Soon it was established that within existing conditions none of the existing methods could be used.

3.5 PILOT SURVEY DEVELOPMENT

Pilot survey was conducted to know the respondent's view on our composed questionnaire. First draft of the questionnaire was prepared on the basis of the activities involved in rehabilitation of M2.It was shared with the project managers of M2 as well as with academia It was having some shortfalls. First of all it was quite lengthy, consisted of 347 questions and 19 pages Moreover, it was without personal / demographic data , Seeing the extra ordinary length of the questionnaire certain aspects like quality of plant , machinery, material and weather etcetera were skipped. After a lot discussions and continuous rehashing first questionnaire was formulated. These categories were inclusive of "any other factor / sub factor to provide the space for descriptive input from the respondent. After receipt of the first response questionnaire was further rehashed. Open ended questions were skipped as these were not answered.After receiving the observations through comments/forms during pilot survey and discussions with field staff and academia. Several important factors were identified which has significant bearing on quality performance but the problem of the lengthy questionnaire was still there. In fact execution is such a level that one has to go to the minutest details. Solution of the problem came in the form of assumptions. Since it was not possible to cover each and every activity so questionnaire regarding base and sub base were skipped to avoid repetition of the similar type of questions. During the rehabilitation of M2 shoulders were not rehabilitated all along so it was also skipped to reduce the number of the questions. Not a single question regarding JMF and activities before it e.g. storage, drawings and design etc. were made part of the survey. Relevant tests / inspections and safety requirements were considered as known to everybody. Now, questionnaire was not only reduced to 122 but also reframed in a better way.

3.6 MAIN SURVEY DEPARTMENT

Now the questionnaire started becoming smart and comments related to the length and layout of the questionnaire got vanished. Continuous scrutiny and assessment were the key contributions in improvement and refinement of the questionnaire. As the first aim of study was to identify the factors (main activities relate to execution) and sub factors (activities contributing towards main activities). Therefore 10 important categories were identified and 98 x sub-factors were listed that sufficiently covered those categories. These sub-factors were taken from literature review, academic discussion sand field experiences of the people. Respondents were asked

about the safety practices being followed by their companies and on their projects. These factors were organized into 10 categories and questionnaire was developed to evaluate the current level of practice being followed in Pakistan. After development of questionnaire it was again circulated to PhDs in transportation engineering and persons who remained involved in rehabilitation of pavements specially, M2. Except for minor changes the questionnaire was validated by all the experts. After reaching to this stage the questionnaire was uploaded on Google form website. It was comprised of two sections containing 2 parts and having 122 questions. First part dealt with demographic data (in descriptive form)/ organisational data (Yes/No) and contained 14 questions (Attached as Annexure - A). Second part pertaining to on site construction practices and was divided into 10 categories these were identified from literature review and field survey. These were considered to have significant effect on quality of rehabilitation of pavements. . Respondents were required to answer on a Likert scale of 1 – 5. Design bases were initial studies that had this similar method (Farooqui 2008, Ng et al., 2001). This part contained 98 questions (Attached as Annexure - A).

3.7 SAMPLE SIZE AND RESPONDENT'S CATEGORIES

In order to get the true picture of a population a sample should be true representative of the population. There are several techniques for selecting the samples. For this study random sampling method was used to minimize any bias in sampling. This data was distributed among 179 professional of different categories (Figure 3.1) including project managers, site supervisors, students, consultants, foremen, administrator, academia, plant and machinery operators. 120 Performa were received giving a response of 67%. According to Black et al, 2000 a response percentage of 30 % is good for surveys in constructions industry. Further information about the respondent is shown in Figures 3.2 & 3.3. Finally, a check list was attained the after gradual improvement. This study was carried out to establish the initial validity of the instrument which was later confirmed by statistical analysis. This data was then compiled and statistical analysis was used for developing the checklist.

3.7.1 Reliability

Often referred to as internal consistency reliability is the measure that how much contradiction lies with in the instrument. It measures that if the factors generally measure the same construct produce same scores. To ensure the validity of the results

chronbach's alpha test was applied. Use of Chronbach's Alpha coefficient was quite helpful. Ranges of the coefficient are given in table 3.1 (George, 2003).

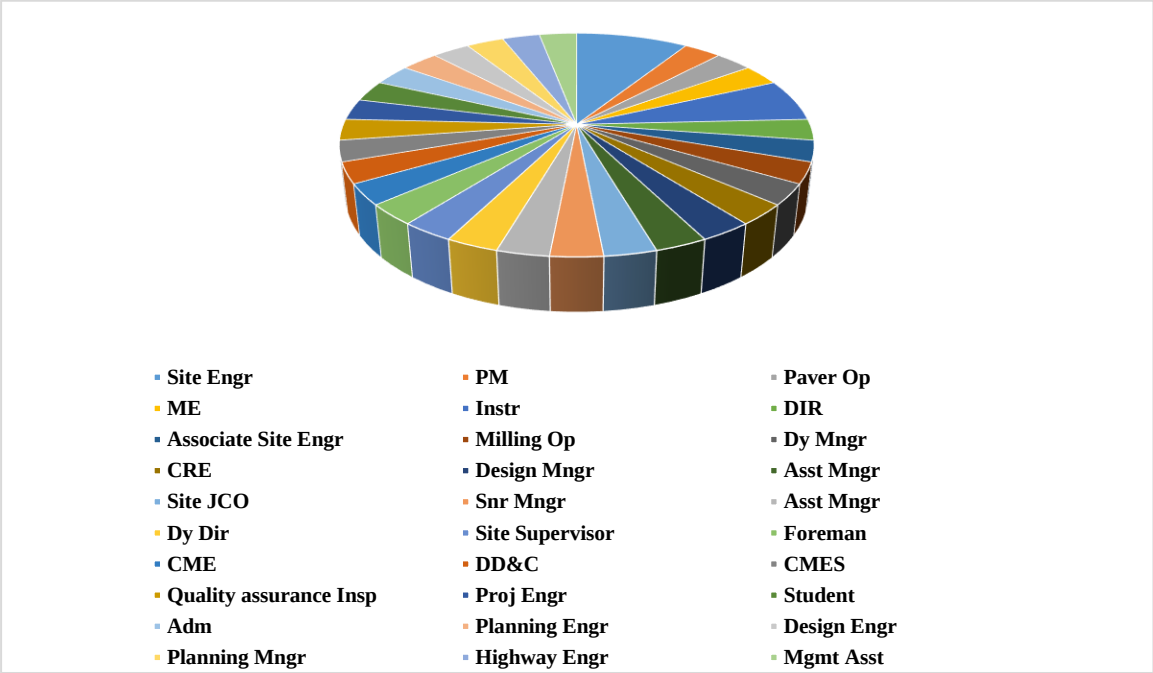


Figure 3.3; Organizational Data

Table 3.1;Chronbach Alpha Values

Coefficient Value	Internal Consistency
$\alpha \geq .9$	Excellent
$.9 > \alpha \geq .8$	Good
$.8 > \alpha \geq .7$	Acceptable
$.7 > \alpha \geq .6$	Questionable
$.6 > \alpha \geq .5$	Poor
$.5 > \alpha$	Unacceptable

All the data of the responses received from Google forms is converted in excel sheets through automation. Therefore, validity of data through chronbagh's alpha soft ware was ideal to use. Results of Chronbach's Alpha reveals that the reliability of data is 0.96. Hence, trust on our data was further enhanced after seeing the validity of data. Our next stages of the thesis were on sound foundation of correct data. It was a great comfort zone for further working of the research.

3.8 SUMMARY

This chapter explained that how a methodology was devised after establishing the objectives and going through the existing body of knowledge. Main activities affecting the quality in execution of pavement rehabilitation were identified from literature review and site visits. After identification these were shortlisted with consultation of field staff and academia. Pilot study, interactive sessions with academia and field staff, development of questionnaire were the logical sequence toward results and analysis stage. A method suited to our needs was devised for quality evaluation. This method not only suits our need but can be implemented with minimum delay. It can also be used in preparation of checklist.

CHAPTER 4

RESULTS AND ANALYSIS

4.1 In order to assess the in depth situation, data analysis was carried out to see the broader picture as well. In this chapter findings of different aspects related to rehabilitation of pavement will be discussed and results will be analyzed. Combined results of significant findings are tabulated below.

4.2 ANALYSIS OF ORGANIZATIONAL MEASURES

Graphical representation of results is given in Figure 4.1:-

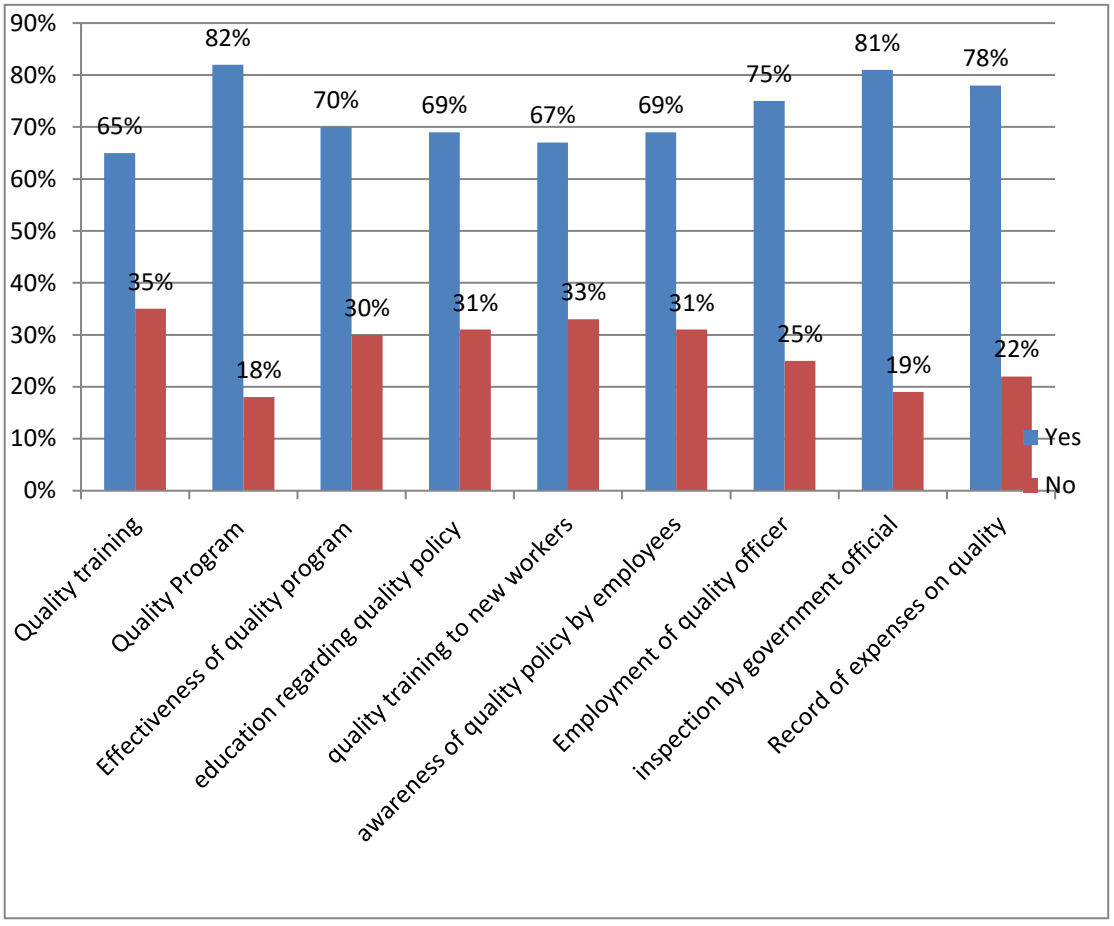


Figure 4.1; Prevalence of Important Organizational Measures

4.2.1 Discussion

Analysis of above data provided in depth view of the actual situation on ground. Despite of the fact that a lot of effort has been made to improve the quality in execution of rehabilitation but the ground realities are deplorable. Analysis of above data along with the findings is discussed in succeeding paragraphs.

4.2.2 Quality Training

Results showed that 65% of the respondents had undergone quality training which shows that general awareness exists. However, same is not the actual picture as the difference between management and quality was not clear, in most of the cases. Which clearly indicates there is gap between the theoretical knowledge and its practical implementation.

4.2.3 Formal quality Programs and Their effectiveness

82% Individuals received quality training and 18% considered the quality programme ineffective. Hence, despite of the availability of qualified and aware persons. No fruitful results can be obtained with in effective programmes. In absence of heed during execution, quality measures can neither be implemented nor enforced.

4.2.4 Quality Departments for education of quality

As far as FWO is concerned 31% said that their companies had no formal quality departments. Mostly companies in Pakistan are small which hire labour as per requirement. Small size of the company doesn't justify an independent quality department. When respondents were asked about the details of their quality department they just mentioned the name of their training institutions.

4.2.5 Employment of quality Officers

As per feed back performa 75% FWO outfits employed full time quality officers on site. On ground the situation is a bit different. Actually, managerial and supervisory staff was considered as quality control staff. Results show that companies with quality departments employed quality officers on site. Employment of quality officer that report directly to top management are considered very effective in improving the quality standards of a company. In M2 it was done a such, rather more than one consultants were responsible for quality and safety. Even executing agency i.e. FWO was having Bin Nadeem associates as its own quality consultants.

4.2.6 Cost of quality Equipment

It was alarming to find out that in public sector cost of quality equipment was never included in the contract price. 100% of the respondents said that no fund for quality is kept aside in road projects. However some foreign funded projects had earmarked some share for better quality.

4.2.7 Quality Inspection

Factories Act 1934 does allow for provision of inspectors and gives full liberty of access. However this matter has been made provisional under the devolution of authority to provinces. Some inspectors usually visit factories but none visit construction sites as these do not fall under there purview. Furthermore the only officials that do visit are from consulting firms like NESPAK, WAPDA , FWO and NHA on their own projects. During interviews it was established that as common practice, consultant is considered responsible for ensuring quality practices on site. It is amply clear from the response of survey as well.

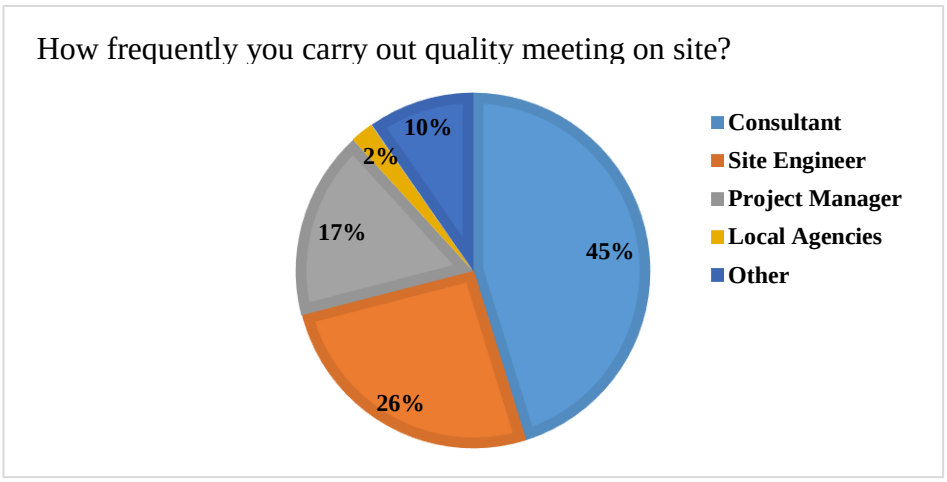


Figure 4.2 Responsibility of Quality

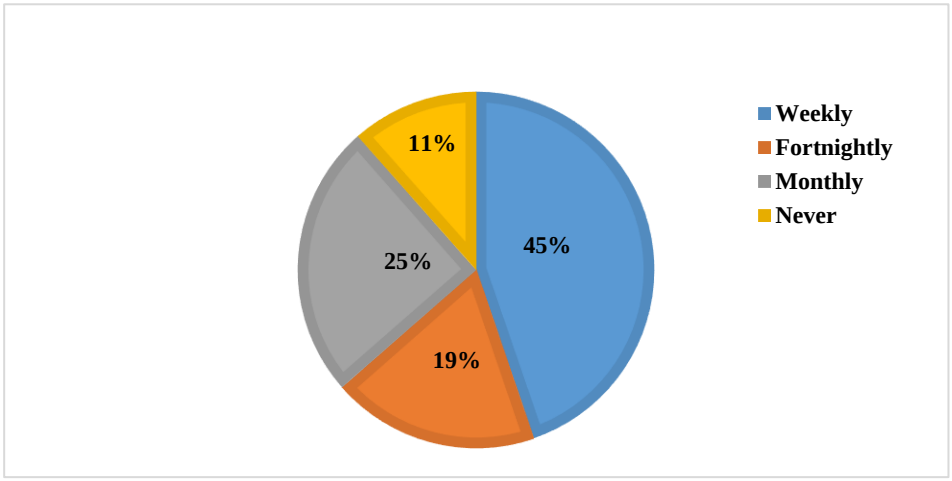


Figure 4.3 Frequency of Meetings

4.3 ANALYSIS OF SURVEY RESPONSE

4.3.1 On Site Quality Practices

For this part the most common and frequently encountered rehabilitation activities were considered. The selected 10 categories (Table 4.1) ensured that a quality friendly environment is a must for all executers. Respondents were asked to provide information as per questionnaire. Each factor and sub factor will be discussed here with reference to the respondent responses received for that factor/ sub factor.

NO OF SUB FACTORS FOR EACH MAIN FACTORS	
Main Factors	**Sub Factors**
Appropriate Milling methodology	9
Effective drainage system	7
Appropriate Crack repair / patching of milled surface	10
Brooming / cleanliness standard	5
Prime / tack coat (execution / application)	11
Transportation of material within suitable temperatures	8
Good paving practices	13
Execution of joints	12
Good Compaction practices	17
Fulfilment of road opening requirements	6

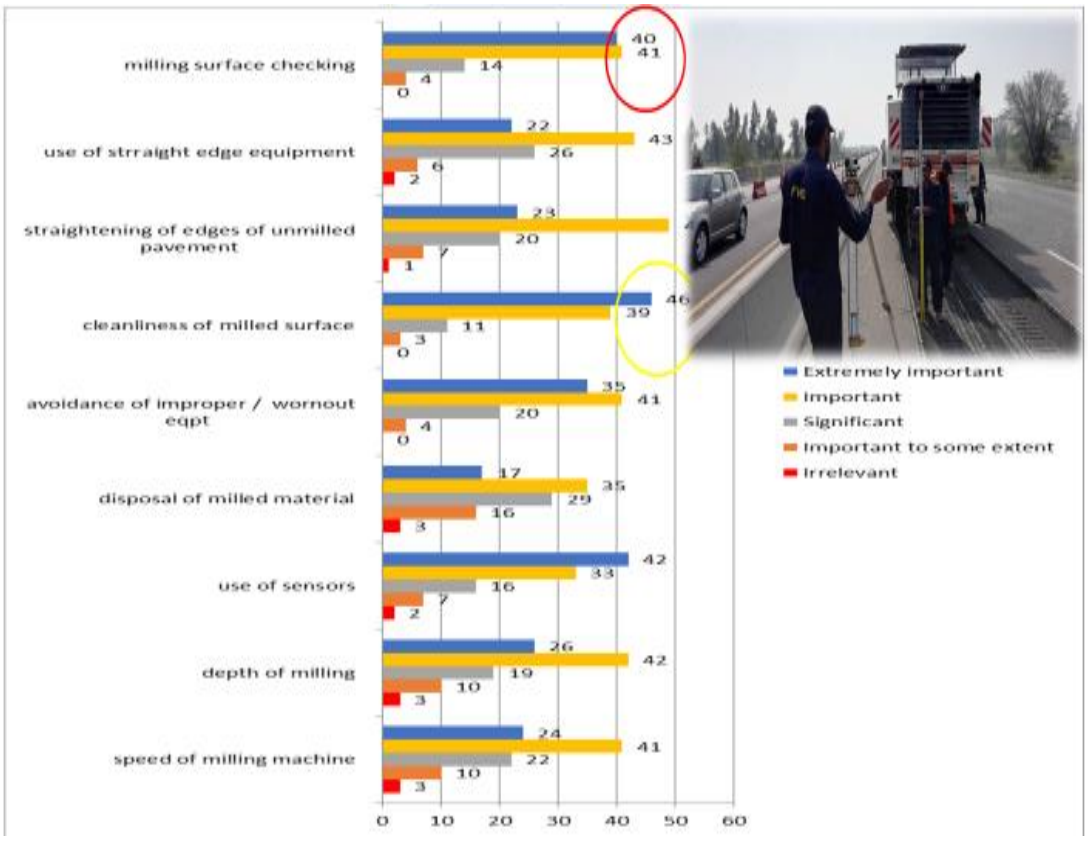
Table 4.1; Main Factors and Sub Factors

4.3.1.1 Milling Methodology

Earlier roads used to be pulverized / kneaded for rehabilitation. After rehabilitation of M2 by milling method, it has become an iconic practice for rehabilitation of pavements in the country. Milling is the first step towards involvement of quality in execution of rehabilitation of pavements. Respondents were asked to provide information about 9 basic considerations in milling for execution of good quality of milling work. Most important sub factor for milling is considered the cleanliness of the milled surface (46%) and no respondent considered it irrelevant and rightly so because presence of mud/ dust invites growth of vegetation and weakness in bonding of the surfaces. The loss caused by the lack of cleanliness is normally irreparable or of very high price tag. Therefore, it must be avoided. While, use of

sensors came out as the second most important factor of the respondents. Inspection of the milled surface was considered as third most important factor and none of the respondent considered it as irrelevant. Use of straight edge was considered the important factor by 49 % of the respondents. 81 % respondents considered the inspection of milled surface important and most important factor. 3% respondents considered the speed of milling machine , depth of milling and disposal of the milled material as irrelevant sub factor which could be due to the their consideration as part of standard operating procedures and absence of control on speed of milling machine which is not a reality.

Figure 4.4; Milling methodology



4.3.1.2 Surface Drainage System

Surface drainage system is the most neglected part of our existing reconstruction / rehabilitation projects. Due to absence of this important aspect some of the road becomes flooded in rains. During M2 rehabilitation it was also envisaged that one of the main cause of settlement in Rawalpindi – Chakri segment was the lack of maintenance of drainage system. During the survey 53 % respondents considered the maintenance of cross slope most important activity, followed by cleaning of existing drainage system (39%). In fact if the surface water is not accumulated during execution

stages there are very less chances of its accumulation after wards.57% respondents considered the redressal of design faults as important factor. 3% of the respondents considered the maintenance of cross slope and outlet ditches as irrelevant sub factors which can only be true in water scarced areas like deserts.

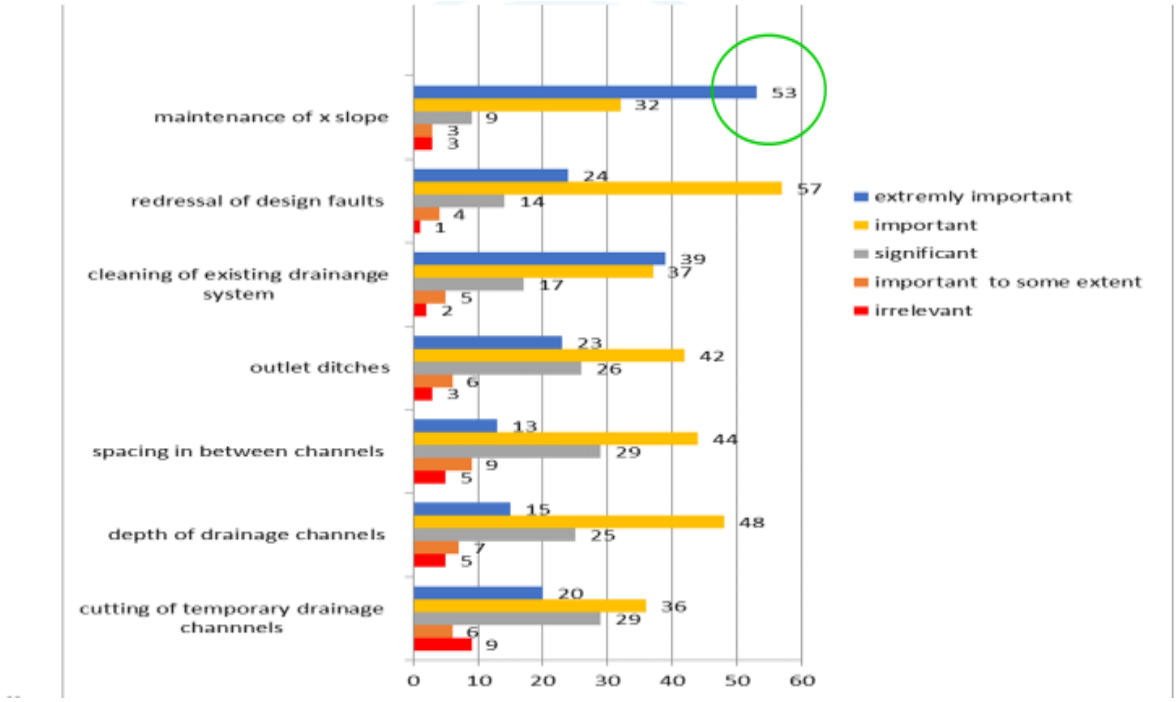


Figure 4.5; Surface Drainage System

4.3.1.3 Crack Repair / Patching of Milled Surface

Although crack repair / patching seems small little activities during execution in rehabilitation of pavements but these can set a side the entire good work, if not executed properly . Poor patching/crack repair are in-fact hidden / slow start of pavement failure. In patching /crack repairing maximum sponsors assigned importance to the compaction of crack/patch (38%). Milling and thickness assurance was considered second most important factor by its respondents (34%). While chamfering of the patch / crack was given most importance by (13%). Cutting, chamfering and ¼'' extension was considered important factor by 46% of its respondents. Cleaning, milling and chamfering was given slight importance by 9% of the respondents. In M2 rehabilitation where it was found that cracks are in abundance in a particular area the novel of user of paver was envisaged. Such areas were milled and paver was used for crack repair. So due to difference of locations of sponsors involved in rehabilitation, variety in responses was observed.

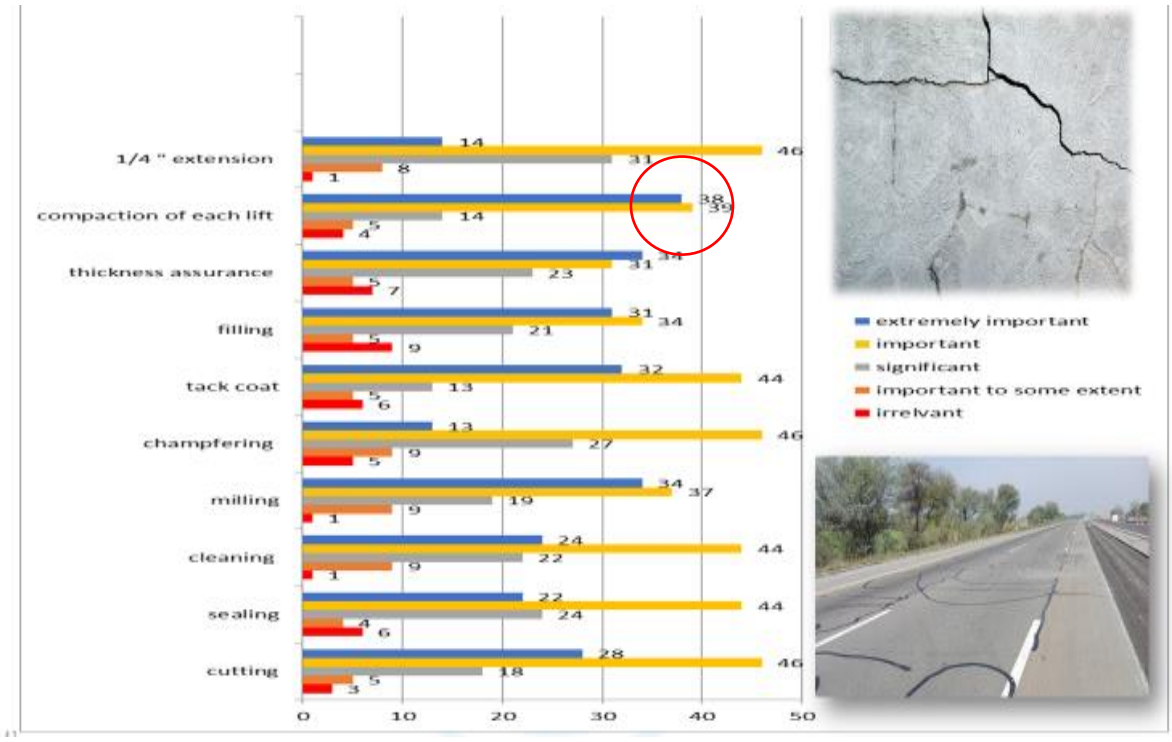


Figure 4.6: Crack Repair / Patching

4.3.1.4 Brooming / Cleanliness

There is a little variety involved in Brooming/ cleanliness. Improper brooming weaken the bond between successive surfaces. Moreover, some times lack of cleanliness may involve production of natural growth in pavements. Mechanical brooming, hand brooming, sand blasting and brooming with hot air are different techniques used in different circumstances. cleanliness was considered the most important sub factor for brooming (44%). While, proper use of equipment, type and size were considered 2ndimportant most factor (41%). Respondents seem more conversant with the brooming techniques. Hand brooming was considered the least significant (15%) as usually involved in rehabilitation of roads except inaccessible areas. Maximum of the respondents (48%) considered the brooming as an important factor before application of tack/prime coat. None of the respondent considered the appropriate equipment, cleanliness of the surface and its execution before prime/tack coat irrelevant in rehabilitation. While surface dryness and proper brooming before application of prime / tack coat were also considered important and most important sub factors by the respondents.

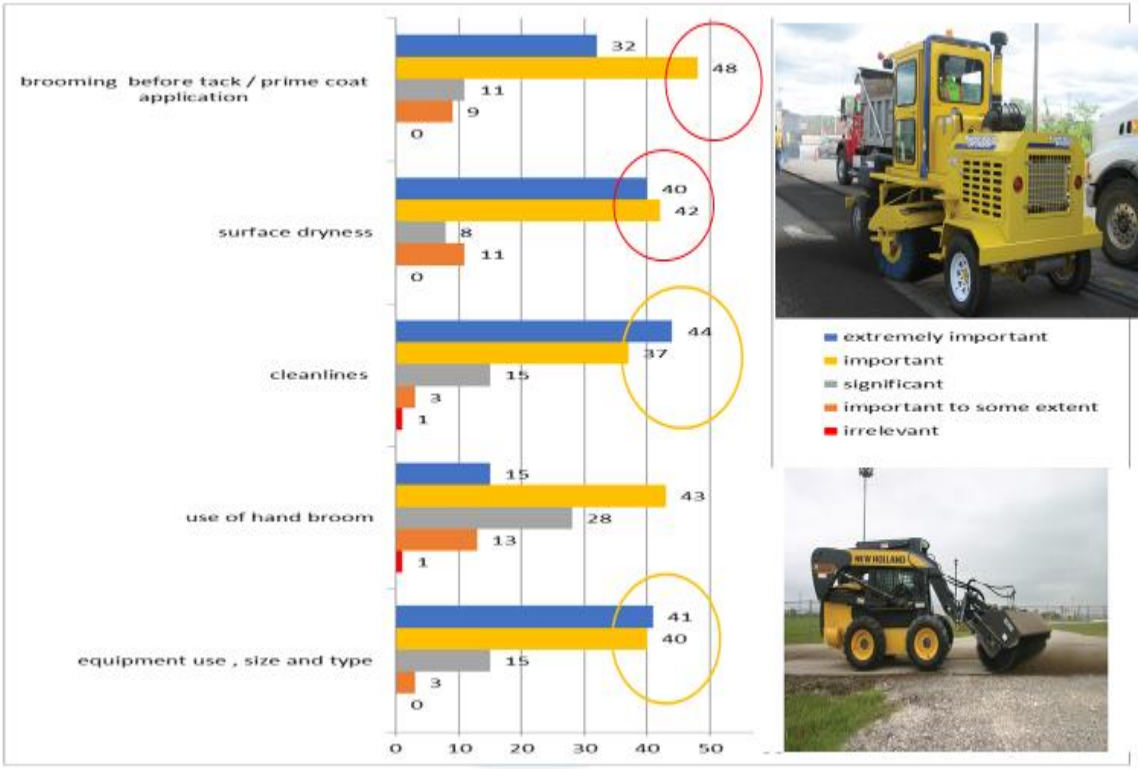


Figure 4.7; Brooming / Cleanliness

Figure 4.8; Prime Coat / Tack Coat

4.3.1.5 Prime coat / Tack coat

Surface cleanliness was considered most important sub factor (59%), uniform distribution of material and quality of material was given equal importance (50%). Accumulative 67% of the respondents considered its application on vertical faces of joints as important and extremely important sub factor. None of the respondent considered the quality of material, uniform distribution and rate of application as irrelevant sub factors.

4.3.1.6 Transportation of Material

In transportation of material adherence to the requisite temperatures was considered most important sub-factor (54%) while none of the respondent considered it irrelevant. Avoidance of lumps and segregation was 2nd most important sub factor (51%). While, 58% of the respondents considered the visual inspection as important sub factor which enhanced to 90% for important and most important ranking followed by allowing of load to break before opening of tailgate (78%). Constant supply of material was considered important and most important by 84% of the respondents so it emerges out as one of most important sub factor. While, allowing load to break was not given much of important, only 20% consider it extremely important.

Figure 4.9: Transportation of Material

4.3.1.7 Paving Practices

In paving practice dryness of rain water was considered most important61% of its respondents, followed by placing of HMA before heat loss (53%). 3rd most important sub-factor by its respondents was proper methodology adoption (50%). None of the respondent considered dryness of rainwater, visual inspection, use of appropriate method, setting of screed and placing of HMA as irrelevant sub factor and they also come out as some of the most important sub factors.

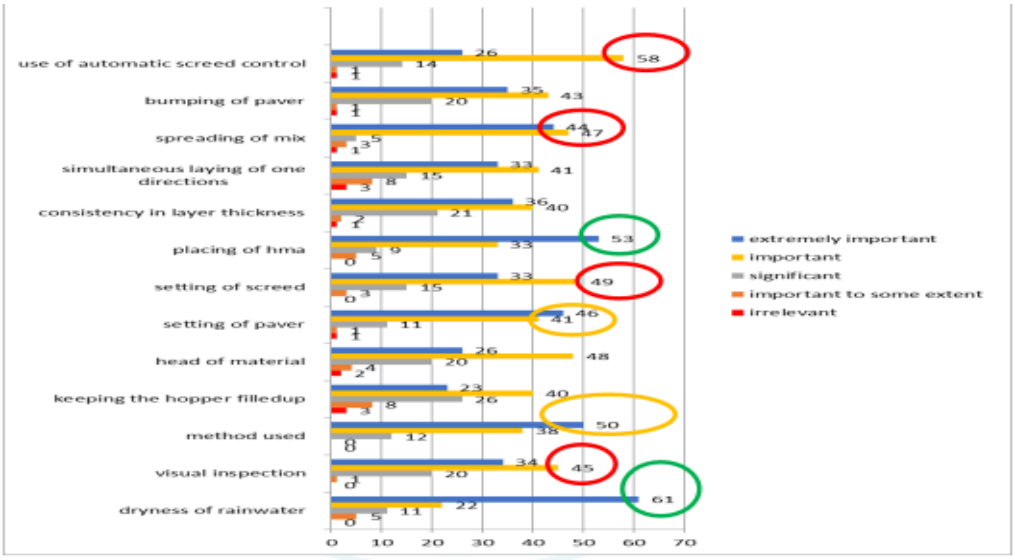


Figure 4.10 ; Paving Practices

4.3.1.8 Compaction Practices

Compaction is an important and critical activity in rehabilitation of pavements. Achievement of 97-98% density was considered most important by 60 % of its respondents. Uniform / slow speed of tandem roller / PTR was considered 2nd most important by 53 % of its respondents. None of the respondent considered the pattern / sequence of rolling, requisite temperatures for different stages of rolling, overlapping, requisite air pressures, avoidance of transverse joints as irrelevant. Lubricating of PTR wheels with release agent , maintenance of asphalt course thickness , use of straight edges for smoothness checking were given more importance than the pattern/ sequence of compaction, avoidance of backlash , continuous monitoring of time and duration of rolling.

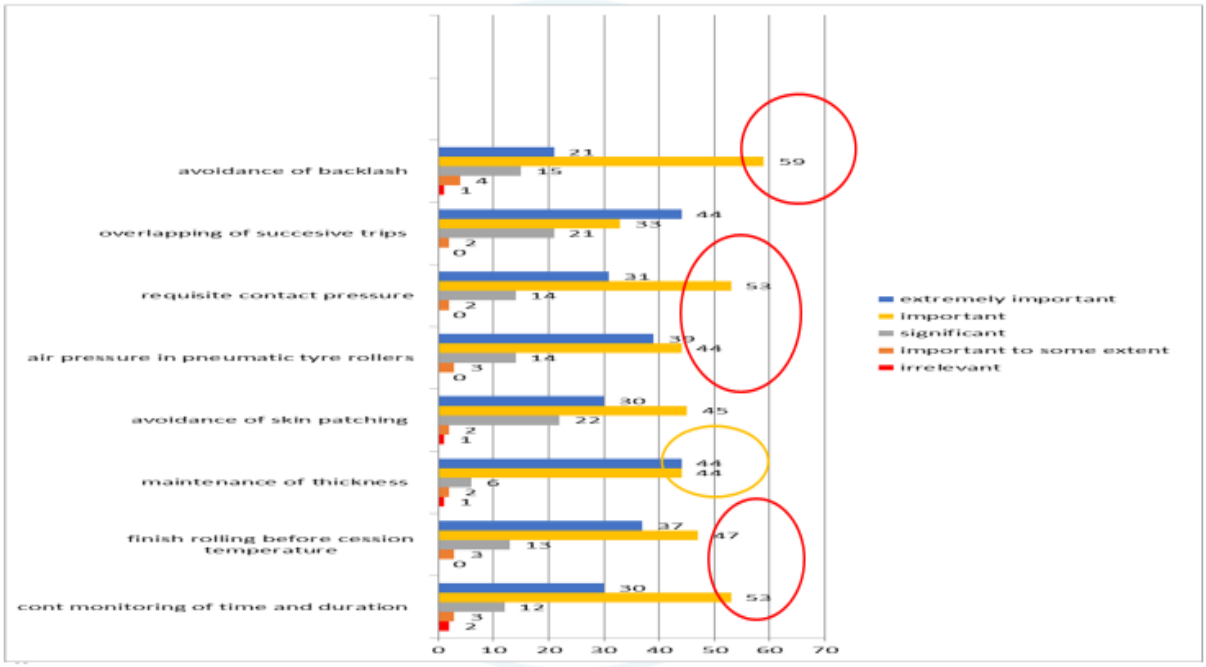


Figure 4.11; Compaction Practices

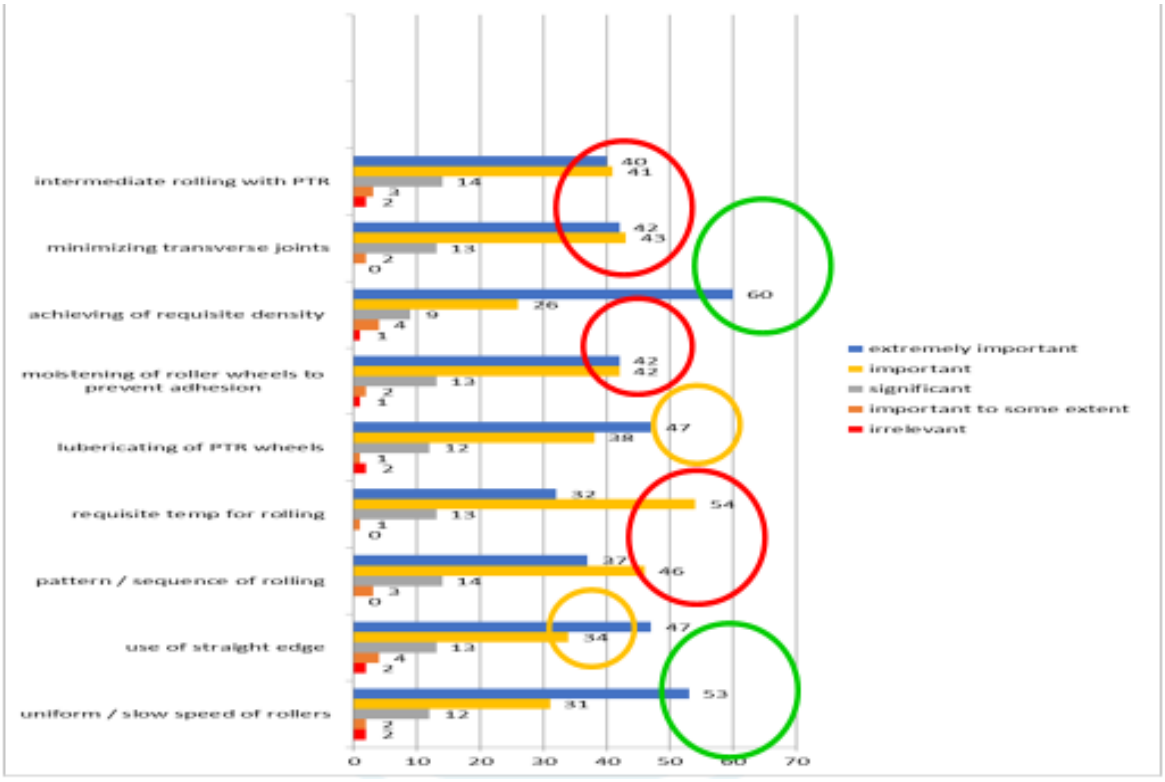


Figure 4.12; Compaction Practices

4.3.1.9 Execution of Joints

In rehabilitation of pavements cold joints, hot joints, longitudinal joints, transverse joints and construction joints are encountered. Cleanliness of the dust was considered most important factor by 54% of the candidate. Whereas, 45% of the respondents considered the application of tack coat on vertical faces of joints as 2nd most important factor followed by matching of adjacent mats in hot joints (43%). Staggering of longitudinal joints and offsetting of transverse joints in different layers was considered an important sub factor by 54% of the respondents while 23% considered them as most important factor which is the lowest percentage here . None of the respondent considered the cleanliness of dust , cutting of edges, tack coat on vertical faces of joints , staggering of joints , overlapping and matching adjacent mats in hot joints as irrelevant factor. Cutting of edges with cutter and meeting of overlays in depth and grade emerged as important sub factors.

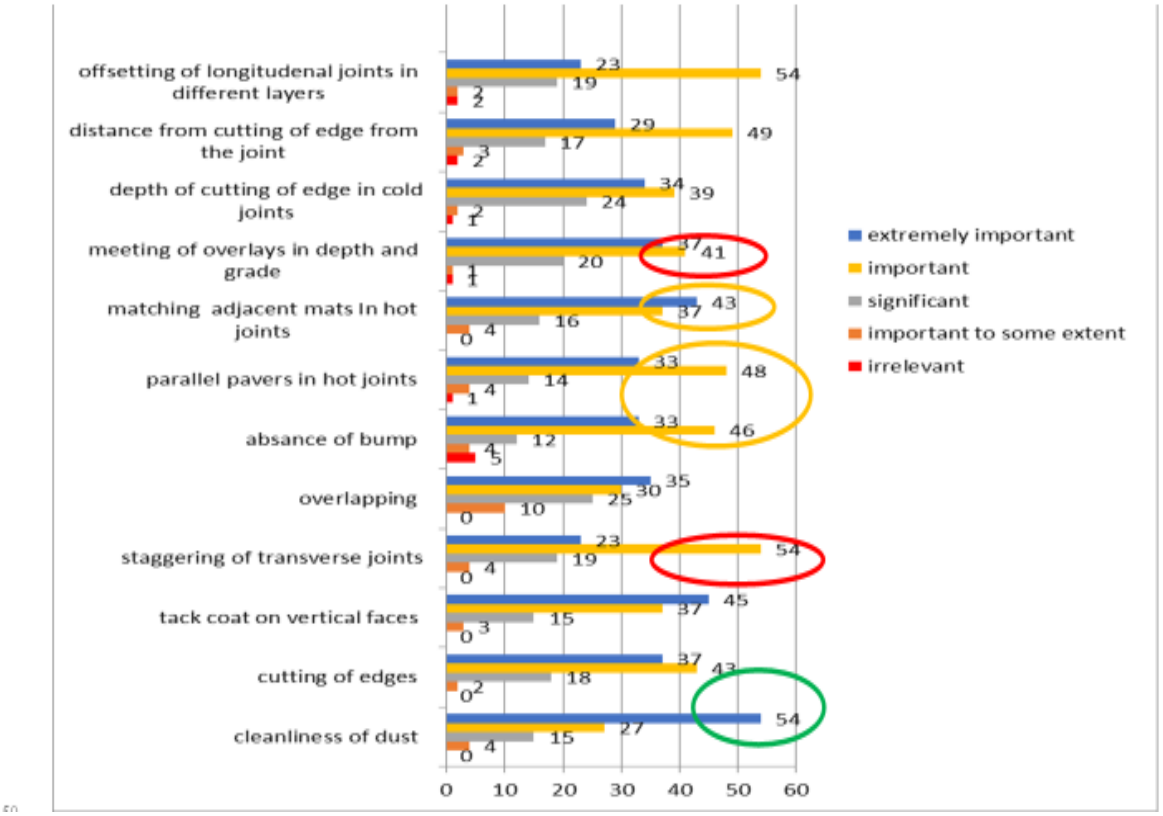


Figure 4.13; Execution of Joints

4.3.1.10 Fulfilment of Road Opening Requirements

Fulfillment of road opening requirements are certain actions which should be fulfilled before commissioning of the road. Mostly importance was given to IRI / roughness (58%). Then 45% considered the rest period of 24 hours to cool down the surfaces up to 40 degree Celsius most important sub factor. 40% considered the absence of longitudinal as well transverse undulation as most important factor. Only 19% of the respondents consider the opening for controlled speed an extremely important activity.

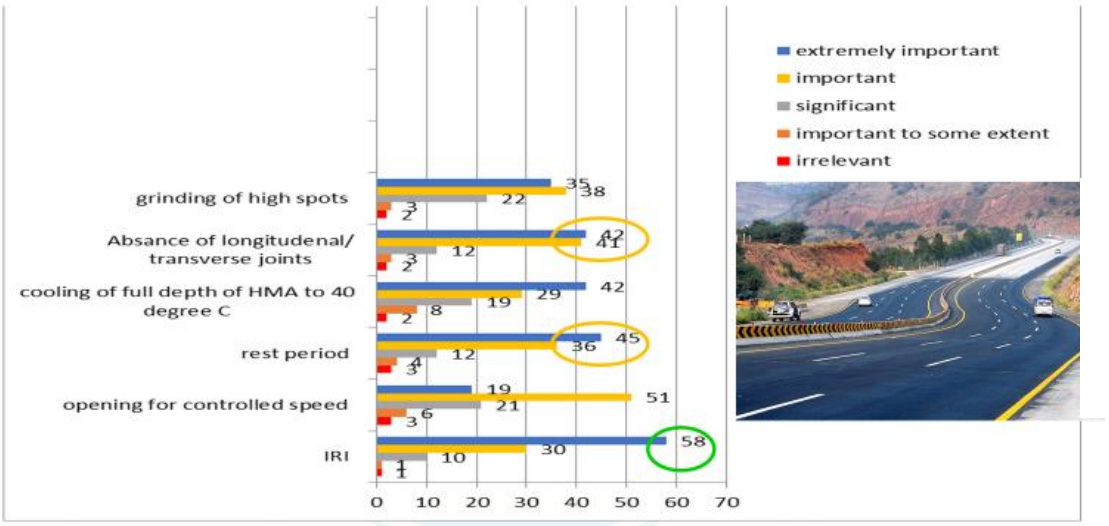


Figure 4.14: Fulfillment of Road Opening Requirements

4.3.1.11 Main factors affecting the quality of rehabilitation of pavements

Irrespective of the weightage given to the sub factors respondents gave the following importance to each main factor. In this portion of the survey 75% of the respondents consider the prime/tack coat application as an extreme important factor, followed by paving practices (60%). While, material transportation was 3rd in extremely important activities. Crack repair/patching and road important were considered extremely important by 25% of its respondents. 50% of the respondents consider that milling, surface drainage system and compaction practices were considered extremely important. 10% of the respondents considered the milling an irrelevant activity. It may be because of relatively new practice of rehabilitation of pavements.

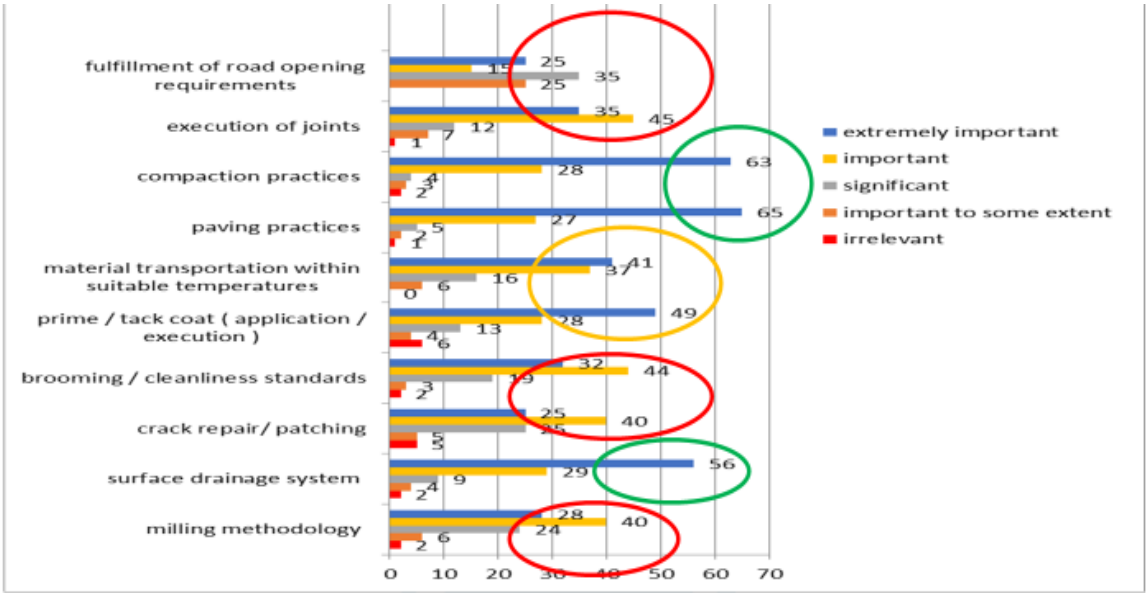


Figure 4.15: Main factors in Pavement Rehabilitation

4.3.2 Analysis of Main Factors

After carrying out the literature review , field survey and questionnaire survey order of priority of main factors for quality in execution of pavement rehabilitation is as mentioned below , While some of the factors are briefly discussed in succeeding paragraphs

a. Good paving practices
b. Good compaction practices
c. Effective drainage system
d. Prime / tack coat (execution / application)
e. Transportation of material within suitable temperatures
f. Brooming / cleanliness standard
g. Execution of joints
h. Appropriate crack repair / patching of milled surface
i. Appropriate milling methodology
j. Fulfilment of road opening requirements

4.3.2.1 Good Paving Practices

92% of the respondent considered it extremely important / important. Paver group manpower is most important in rehabilitation workforce, Substantial pay packages dictates the critical role of paver group. Paver and its functioning is most critical in rehabilitation operations. All activities of rehabilitation revolve around paving operation. Its significance demands checking of surface smoothness after every

15-20 meter stretch. Small little activities have tremendous importance e.g. cross slope, Air void ratio and asphalt layer thickness. Speed of the paver affects the mat thickness. If a paver speeds up it decreases mat thickness. While, on decrease , mat thickness increases. Efficiency of the paver dictates asphalt laying output (Normally 1000 ton per day). Preference should be given to use paver in echelons to avoid longitudinal joints. HMA must be placed with in 1-2 hours of its production. Maximum hauling time is 45 minutes

4.3.2.2 Good Compaction Practices

Literature review and field visits also emphasized on both good compaction activities and good paving activities. Both are interrelated activities. Achieving of good compaction is very difficult without very well paved surface. Quality of very well laid paved surface can be compromised if compaction is not done properly. Timings and duration of compaction have an important role. Best time to start the rolling of HMA is when resistance to compaction is minimum but at the same time capable to support the roller without shoving in HMA. Compaction to continue till desired density is achieved and before cession temperature. Over compaction may cause migration of asphalt to compacted pavement surface. Speed is kept 3mph for steel wheel roller and 5mph for pneumatic tire roller.

4.3.2.3 Effective Drainage System

Most cost effective and less risky to prevent moisture entry /accumulation is achieved by using surface drainage. Islamabad-Chakri segment of M2 was most effected by lack of maintenance of drainage system. Literature review also demanded that significant drainage deficiency should not go unnoticed during survey. Special survey is viable option in that scenario. Tight joint is essential between pavement and shoulders, pavement and gutters/drains. First most important factor (Paving Practices) has also its contribution towards impermeability of HMA by suitable air voids (5-6%) and for gravity flow it is even higher in underneath surfaces. Generally 5% grade and 2% slope is good enough for effective drainage system

4.3.2.4 Appropriate Milling Methodology

M2 rehabilitation spear headed the use of milling methodology in Pakistan on such a mass level. As per survey response milling methodology is highly dependent upon cleanliness of the milled surface and its inspection to see level difference to profile level which seems logical as quality of milling can’t be assessed without seeing the clean surface and its profile level difference. It is used to remove damaged portions of

the pavements. Good milling necessitates good working condition of milling machine. Concept of field staff slow milling brings good milling is not a fact based conclusion.

4.3.2.5 Proper Application of prime / tack coat

In fact, it is a membrane of asphalt binder which provides the glue between layers of new asphalt concrete. It creates monolithic structure which opposes independence of layers. Lack of bonding in between the layers can bring drastic reduction in pavement service life. Temperature is critical sub factor for this, specially $< 15\ ^{0}$c. Its cost is nothing as compare to bond failure. As per survey response for proper execution of prime / tack coat is surface cleanliness is extremely important. In absence of proper cleanliness the imperfection of the prime/tack coats will be disclosed even after a few days .

4.3.2.6 Transportation of Material within suitable temperatures

Although transportation of material does not involve directly in quality of execution but without arrival of Hot mix asphalt (HMA) at requisite temperature and without segregation/lumps, achieving of good quality in Asphalt laying is almost impossible. Small little precautions e.g. speed of the dumpers, cleanliness condition of the truck bed and avoidance of lean/dull appearances, true placing of HMA and avoidance of bumping of the truck in paver do have the affects. As per survey results requisite temperatures and avoidance of segregation / lumps were two most important sub factor for the efficient transportation of the material.

4.3.2.7 Brooming / Cleanliness standard

Adherence to brooming and cleanliness standard is a prerequisite for asphaltic courses / bituminous coating. During the sites visits field staff also emphasized on it. They were of the opinion that mud and water joins to form natural growth that destroyed the pavements. Therefore, cleaning and drying of the crack is a must for perfect / bonding. As per survey response proper use of equipment and cleanliness of the surface were the two top most requirements for achieving of the good brooming standard. Thus, good quality of equipment and perfect cleaning have hand and gloves relationship. Dryness of the surface and brooming before every prime/tack was necessitated.

4.3.2.8 Execution of joints

On large scale rehabilitation execution of joints is most laborious job because each joint require tremendous effort to cope up with good IRI requirement. Some of the seasoned foreman / operators went for compaction even in transverse direction to achieve the targeted IRI. Joints could be cold, hot, longitudinal or horizontal.

4.3.2.9 Appropriate crack repair / Patching of milled surface

Badly cracked pavement section, especially those with pattern cracking must be patched / repaired. Milling and paving was also made one of the option for the areas where extensive crack repair / patching was involved. Working cracks require sealing while no working require filling. Cracks invite oxidation and further hardening of HMA.

4.3.2.10 Fulfilment of Road Opening Requirements

Respondents graded it as least important factor but it should be kept in mind that it still has the vote of 60% of the respondent as most important / important factor. Only small little remedial measures like clearance of loose material and spreading of sand etcetera are possible at this stage. It is delivery stage of all execution practices. If all the good engineering practices are followed no problem is likely to come while commissioning the road. At controlled speed road can be opened for traffic in earlier time frame but not before cooling of all asphaltic layers to suitable temperature. IRI is its most important factor as good IRI means most of the rehabilitation practices have been followed in true letter and spirit.

Table 4.2; Main Factors in Order of Priority

MAIN FACTORS FOR PAVEMENT REHABILITATION			
Order of Priority	**Score given by respondents**		
	Extremely Important	**Important**	**Total**
Paving Practices	65	27	92
Compaction Practices	63	28	91
Surface drainage system	56	29	85
Execution of Joints	35	45	80
Material transportation within suitable temperatures	41	37	78
Prime / tack coat (application / execution)	49	28	77
Brooming / Cleanliness standards	32	44	76
Milling methodology	28	40	68
Crack repair / patching	25	40	65
Fulfillment of road opening requirements	25	15	40

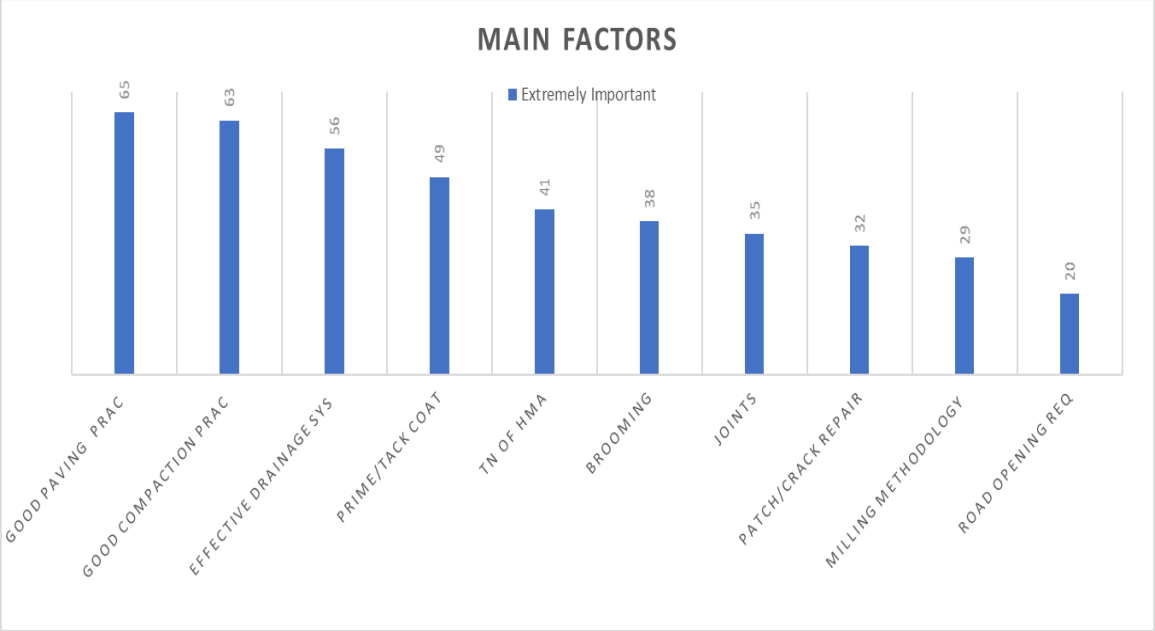


Figure 4.16; Importance of Main factors in Order of Priority

4.3.3 Analysis of Response to Sub Factors

Total sub factors were 98 and Minimum number of respondents required to represent sub factors of all main factors were77. Depending upon respondents for extremely important and important number of sub factors qualified for top bracket of important sub factors are 59 (Green 10 , Yellow 22 and Red 27). Further criteria of each category is explained in succeeding subparagraphs and Table 4.3 :-

Table 4.3; Categories of Respondents

Category		**1st**	**2nd**	**3rd**
No of Respondents		**77**	**77**	**77**
Color Code		**Green**	**Yellow**	**Red**
Score	**5**	**More than 50**	**≤ 50but in majority**	**≤ 50 but in minority**
	4	**26 or <**	**≤ but in minority**	**≤ 50 but in majority**

a. **1st category of selected sub factor (Green)**

No of Respondent for score 5 (extremely important) > 50 in Numbers and accumulative respondents for score 5 and 4 are not less than 77

b. **2nd category of selected sub factor (Yellow)**

Number of Respondent for score 5 are < or = 50 but respondents for score 5 are in majority with less than 50 votes and accumulative respondents for score 5 and 4 are not less than 77

c. **3rd category of selected sub factor (Red)**

Same as case of yellow but number of Respondent for score 4 in majority with less than 50 votes and accumulative respondents for score 5 and 4 are not less than 77%

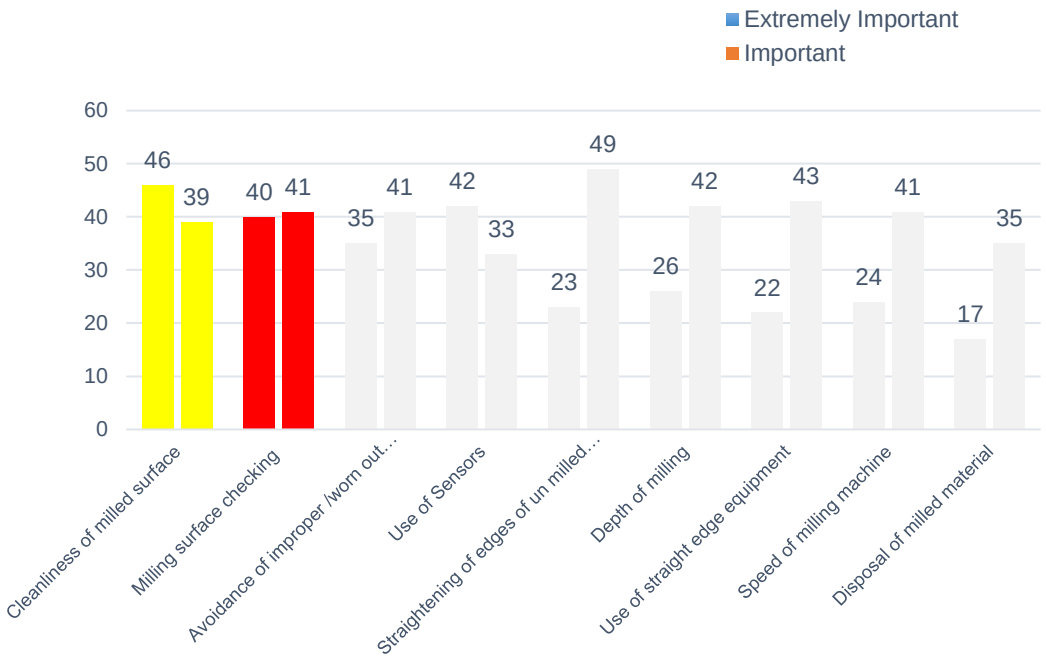


Figure 4.17; Sub factors of milling methodology in order of priority Order

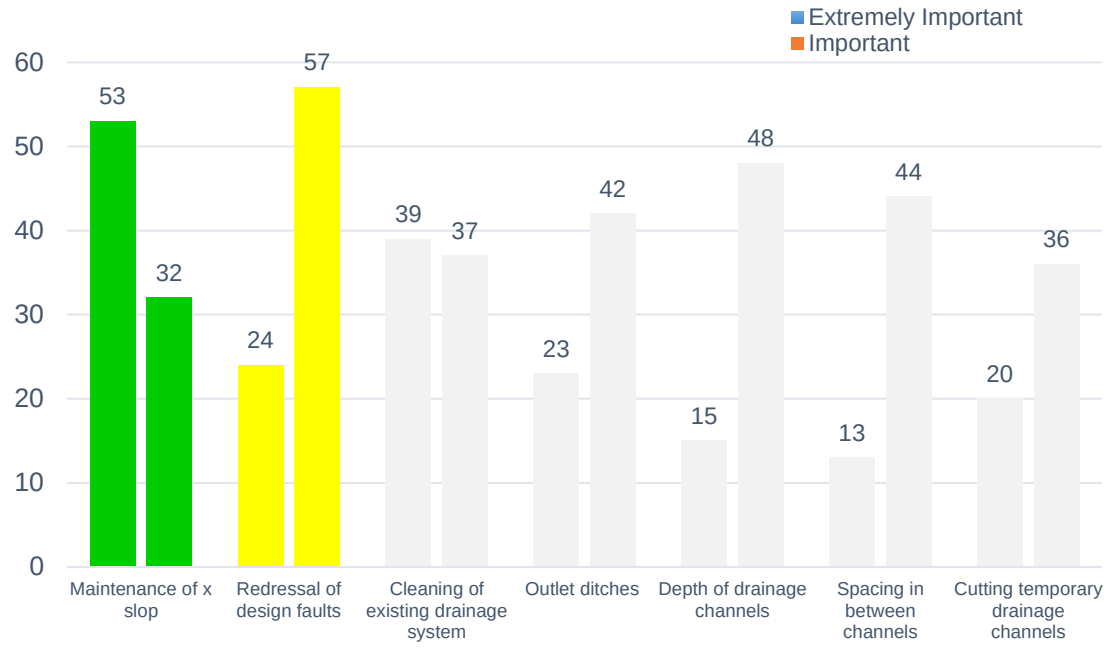


Figure 4.18; Sub factors of Surface Drainage System in Order of Priority

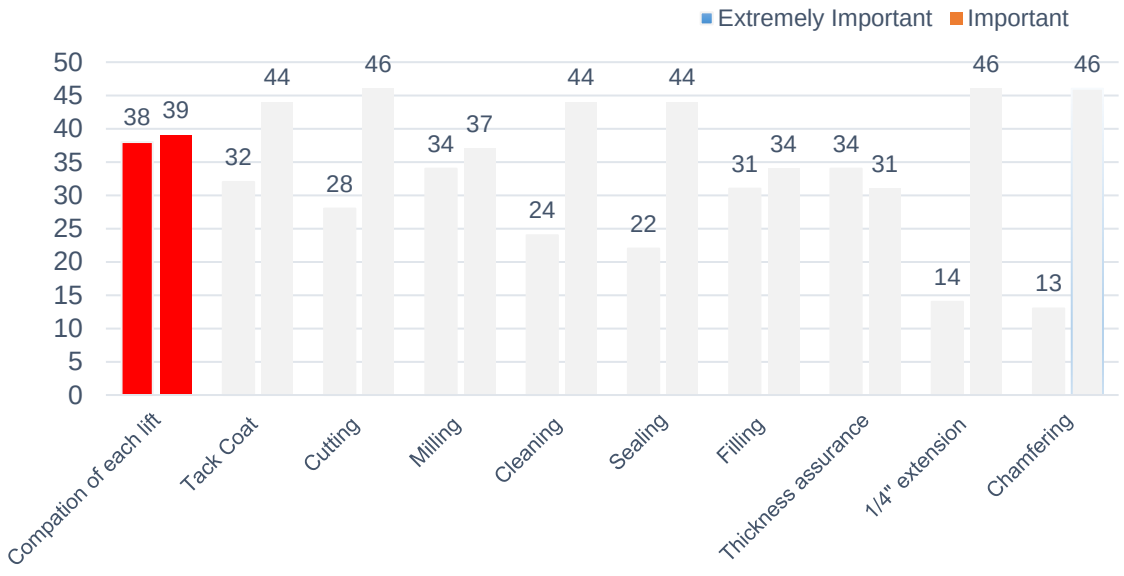


Figure 4.19; Sub factors of Crack Repair and Patching in Order of Priority

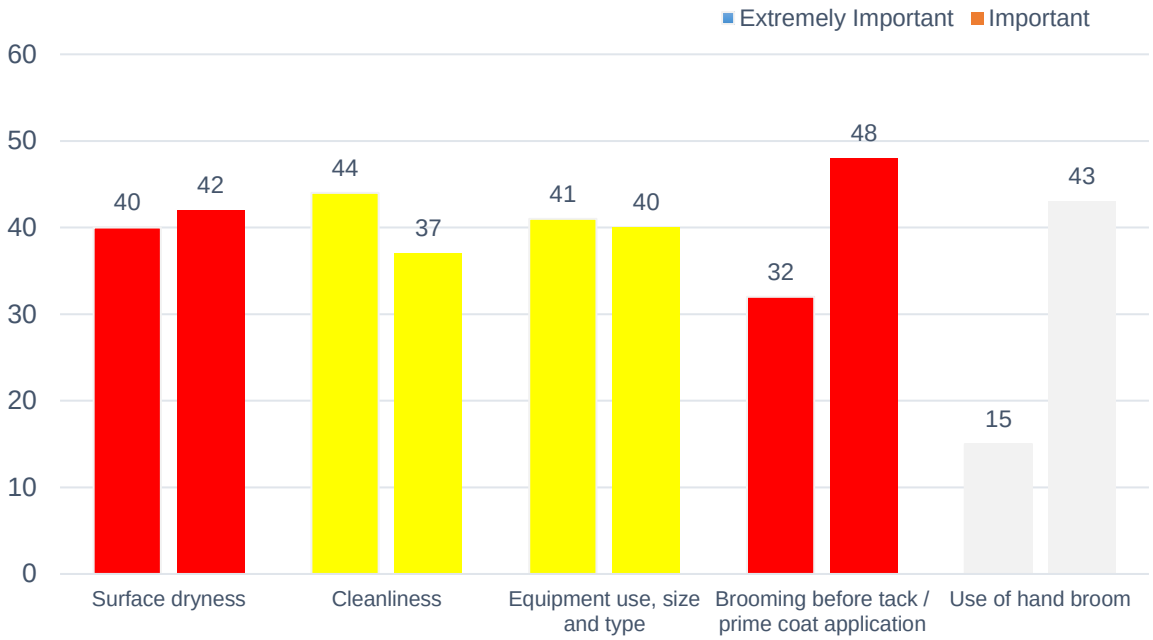


Figure 4.20; Sub factors of Brooming and Cleanliness in Order of Priority

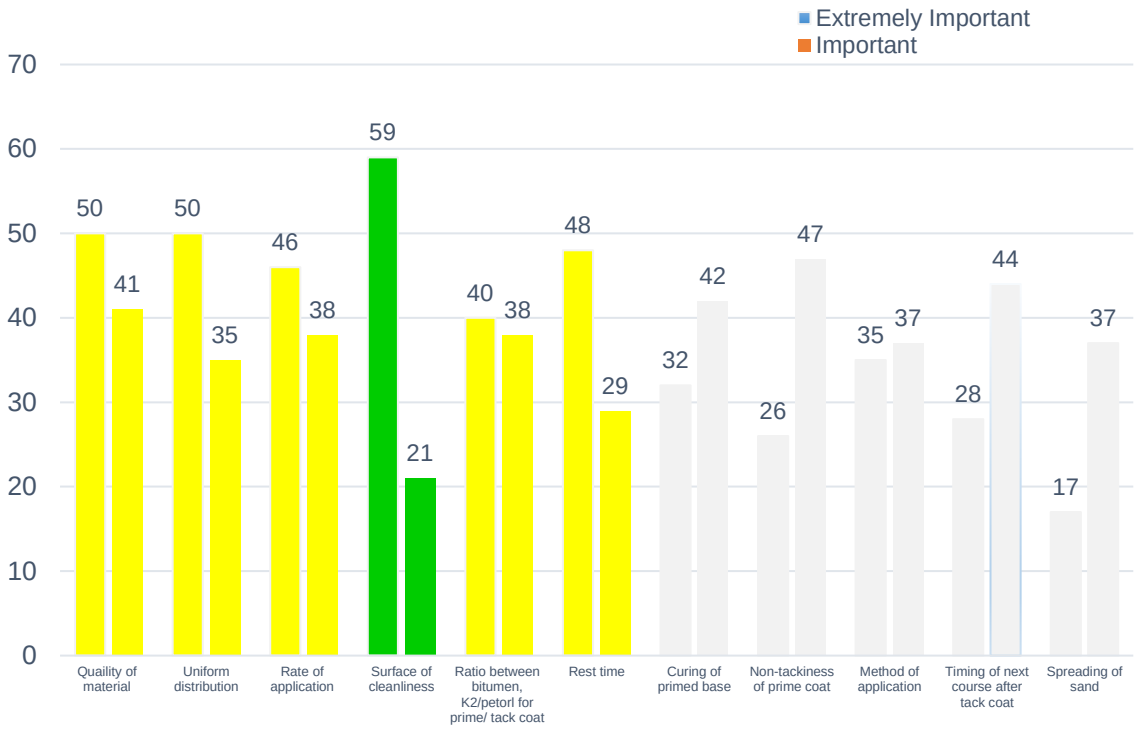


Figure 4.21 Sub factors of Prime / Tack Coat in Order of Priority

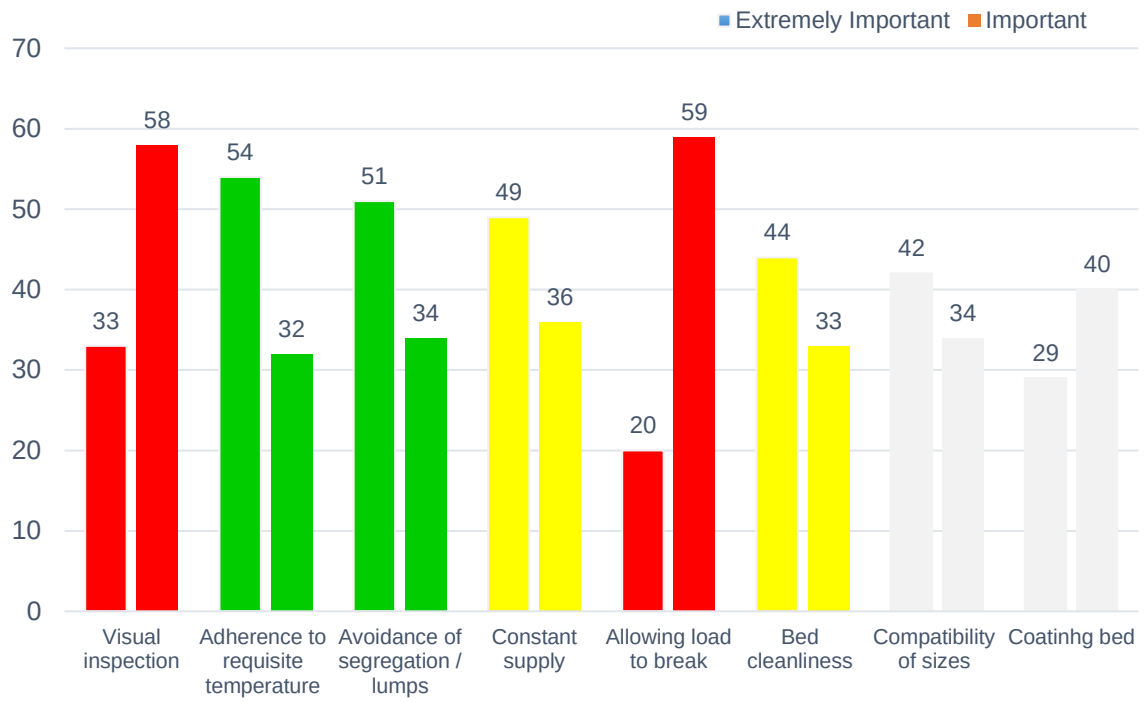


Figure 4.22; Sub factors of Transportation of Material in Order of Priority

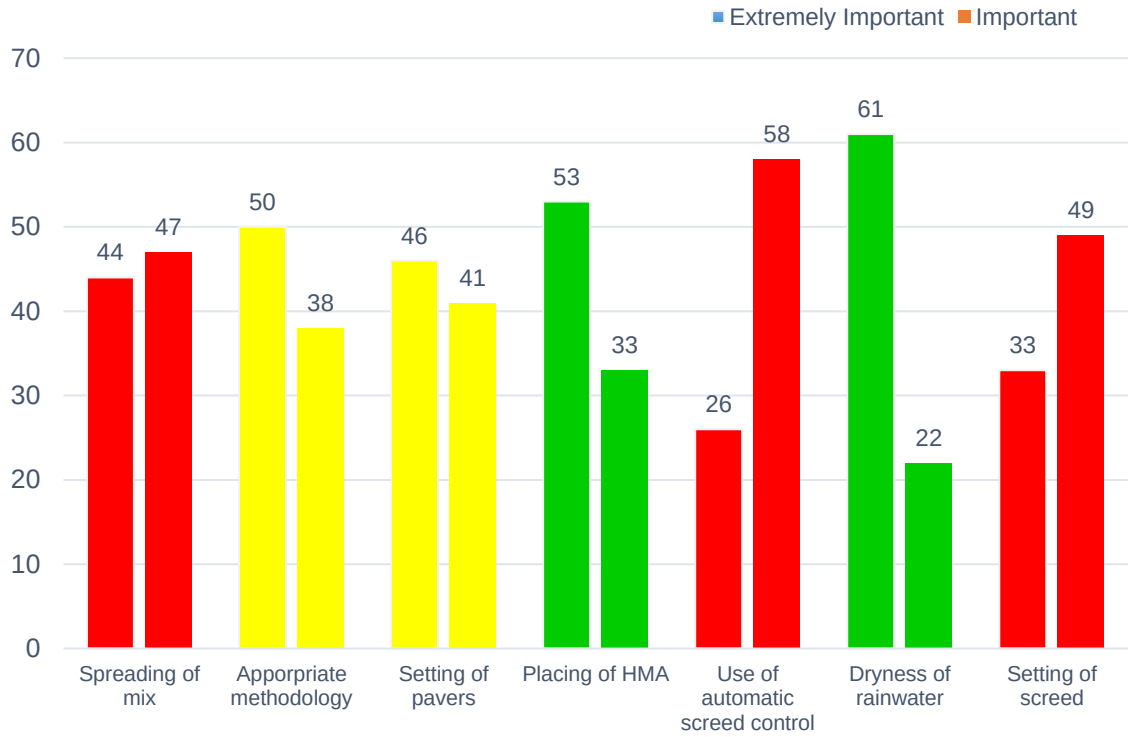


Figure 4.23; Sub factors of Paving Practices in Order of Priority

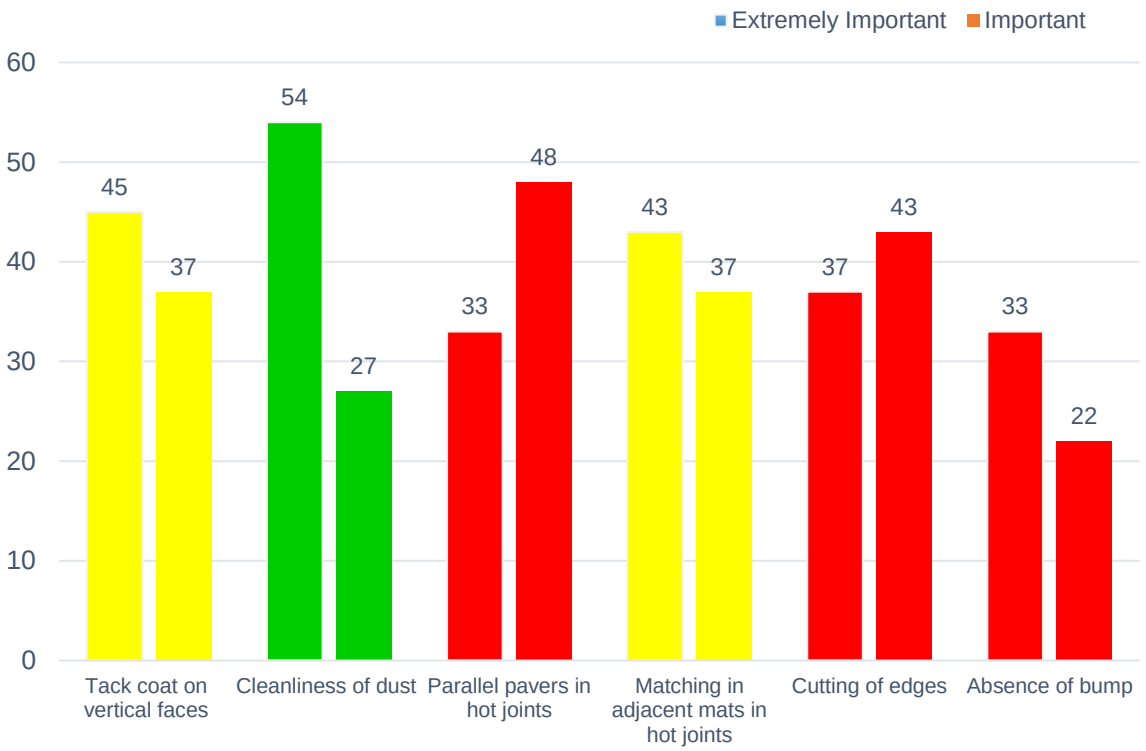


Figure 4.24; Sub factors of Paving Practices in Order of Priority

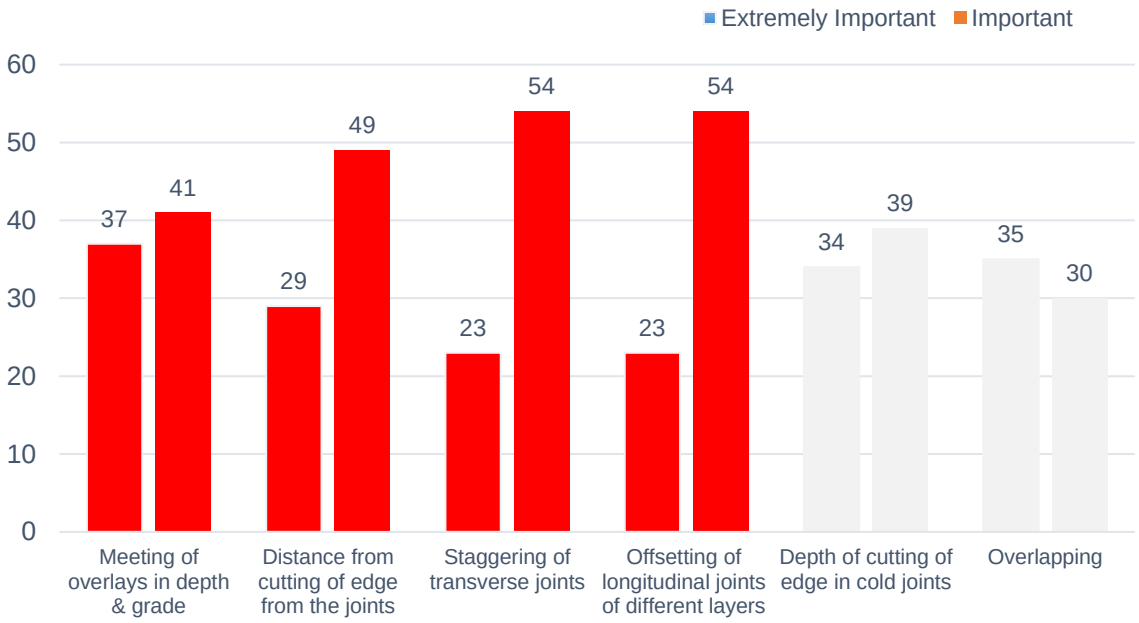


Figure 4.25; Sub factors of Execution of Joints in Order of Priority

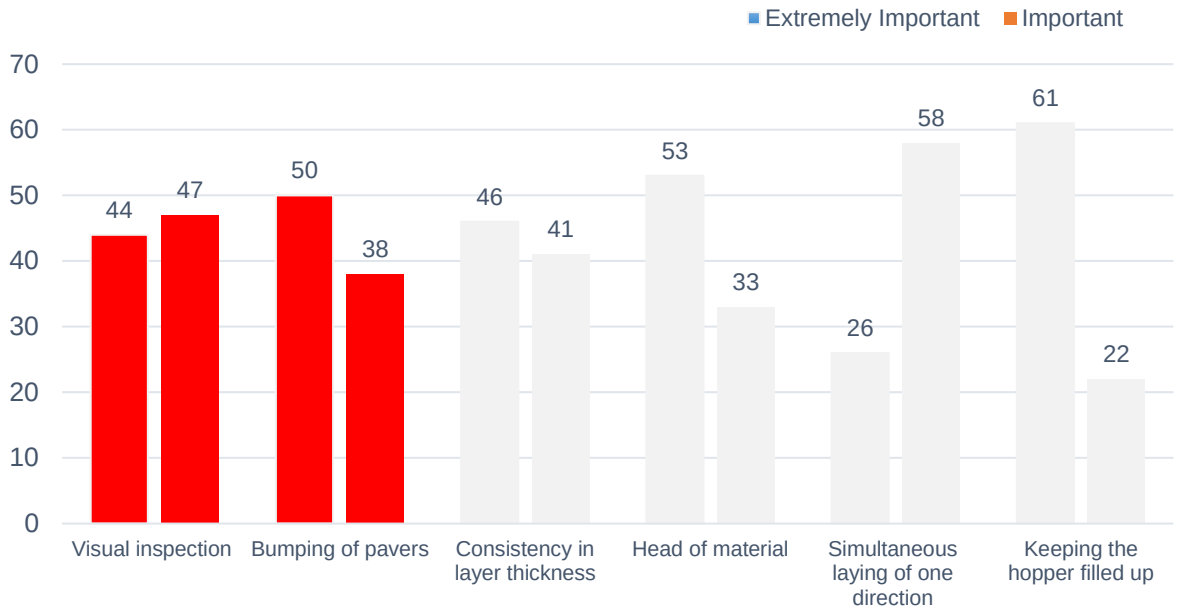


Figure 4.26; Sub factors of Execution of Joints in Order of Priority

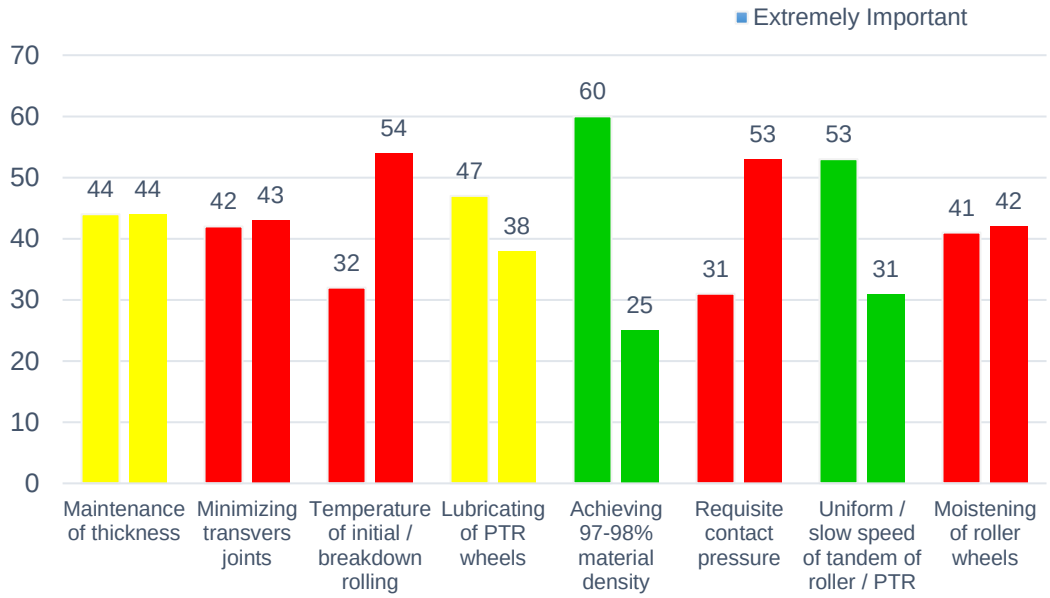


Figure 4.27; Sub factors of Compaction Practices in Order of Priority

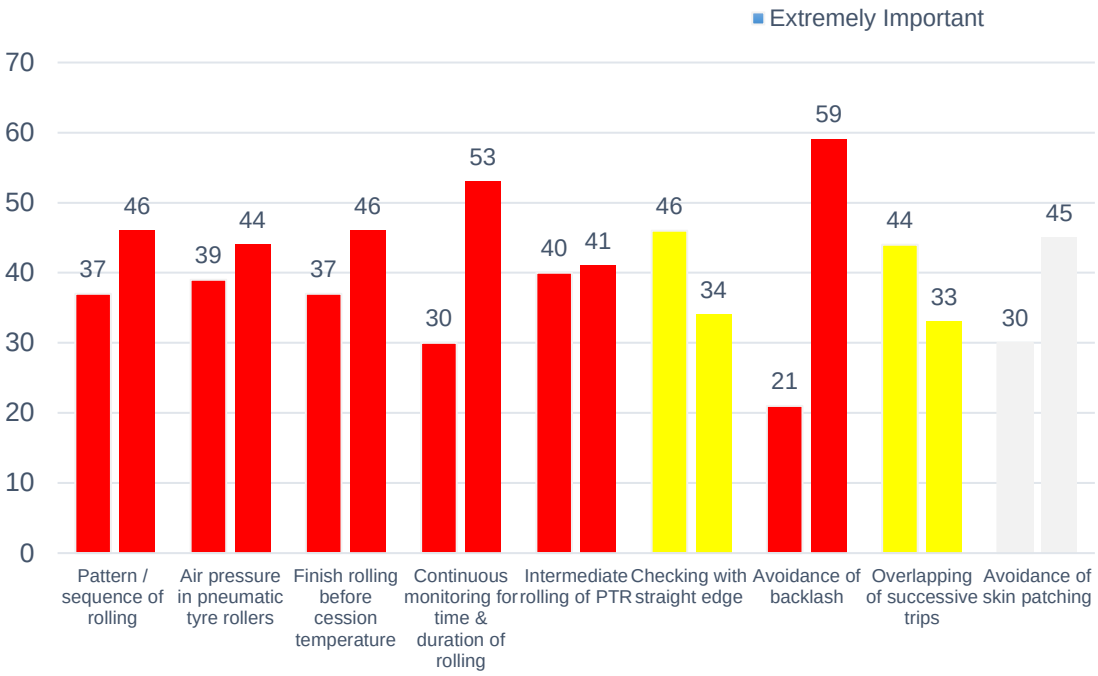


Figure 4.28; Sub factors of Compaction Practices in Order of Priority

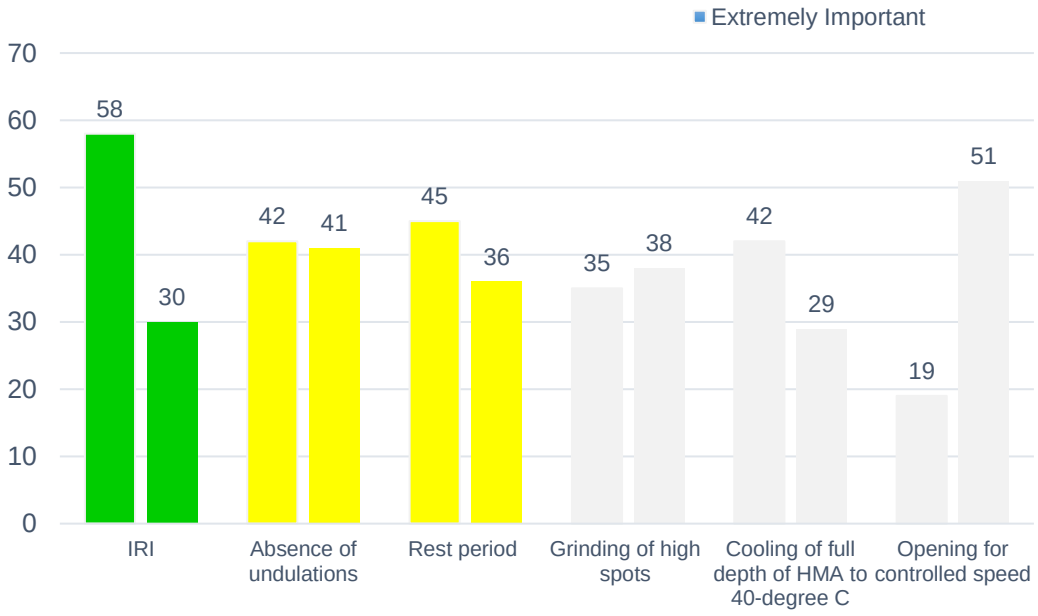


Figure 4.29; Sub factors of Compaction Practices in Order of Priority

CATEGORIES OF SELECTED SUB FACTORS				
	Respondents of Extremely Important			
Respondent	**>50**	**< or =50**		
		Respondents For Extremely Important		
		More	**Less**	
Color Code	**Green**	**Yellow**	**Red**	**Total**
Factor	**No of Sub Factors**			
Milling	-	1	1	2
Drainage	1	1	-	2
Crack Repair	-	-	1	1
Brooming /Cleanliness	-	2	2	4
Prime / Tack Coat	1	5	-	6
Transportation	2	2	2	6
Paving	2	2	5	9
Joints	1	2	7	9
Compaction	2	5	9	16
Road Opening	1	2	-	3
Total	**10**	**22**	**27**	**59**

4.3.3 Analysis for the Categories of Selected Sub Factors

4.3.4 Categories of Selected Sub Factors

a. **<u>Option 1 (Green)</u>**

Top ten sub factors were identified. No sub factors from factors of Milling, Crack repair, Brooming /Cleanliness was qualifying. Good for on academic discussion on shortlisting. Practically, it is not a feasible criteria

b. **<u>Option 2 (Yellow)</u>**

Top 22 sub factors were identified. Representation of brooming factor was missing. Not a suitable option for practical purposes.

c. Option 3 (Red)

Top 27 sub factors were identified. Representation of drainage and Prime / Tack coat was not found. Not suitable a suitable option for practical purposes.

d. Option 4 (All Colours)

Top 59 sub factors were identified. Representation of all main factor has been achieved. This is the only option which is closer to real time scenario. Therefore, it is the recommended option

4.3.5 Order of Priority of Top 10 Sub Factors

a. IRI should be < or = 1.5
b. Achieving of 97 – 98% of laboratory compaction / material density
c. Placing of HMA before heat loss
d. Adherence to the requisite temperature of HMA while loading unloading, laying and compaction
e. Maintenance of design cross slope for surface runoff
f. Avoidance of segregation and lump
g. Uniform / slow speed of the tandem rollers / PTR
h. Removal / dryness of rainwater etc. Prior to laying of HMA
i. Cleanliness of dust
j. Surface of cleanliness / preparation for prime / tack coat

4.3.6 Analysis of Sub Factors (Randomly Selected)

Considering the large no of sub factors only three out of 98 are discussed in succeeding paragraphs.

4.3.6.1 IRI

It is ratio of standard vehicle's accumulated suspension motion divided by distance travelled by the vehicle during data collection. It is standardized index of longitudinal unevenness. It is a concern of both i.e. user and agency because it relates to vehicle operating cost, ride quality and dynamic wheel loads. Functional condition of the pavements can be assessed by ride quality, expressed in terms of IRI. IRI should be < or = 1.5 for qualification of rehabilitation work as it was the minimum requirement in M2 rehabilitation. This was the leading sub factors among all the factors and sub

factors. It was sub factor of road opening requirements. Although spreading of mix according to established grade (sub factor of paving) gets maximum sponsors 91% for score of 5 and 4 (very important and important) but its respondents for extremely important are just 43% against 58% of IRI (87% respondents). During M2 IRI inspection vehicles were used by the FWO for self inspection before visits of the quality inspectors.

4.3.6.2 Achieving Of Requisite Density During Compaction

It is sub factor of our 2nd leading most important main factor. Thorough and uniform compaction is a must for good rehabilitation. Minimum 10 tons steel wheel roller are required in M2 even 14 ton rollers were used. Breakdown Roller speed was kept uniform not exceeding 3 mph. As per NHA specification and Quality management handbook rolling may continue till achievement of 97% of lab density. Density is monitored during compaction by use of nuclear density gauge. Line and grade of the edges of bituminous mixture should not be disturbed. Finnish rolling is used to finish roller marks but must be completed before cession temperature.

4.3.6.3 Adherence to The Requisite Temperature

86% of the respondents consider it most important/ important sub factor. Temperature of asphalt while loading/ unloading should not be more than 163 degree Celsius. minimum air temperature for prime coat is 15 degree Celsius while execution of HMA laying is not permitted at temperature of 4 degree Celsius or less. Mixtures laying and spreading temperature should not be less than 130 degree Celsius. Initial or breakdown rolling temperature should not be less than 120 degree Celsius and finish rolling temperature should not go less than 110 degree Celsius. Temperature of the aggregate not the binder controls the HMA temperature. If temperature of HMA is too high it will have blue smoke. Stiff appearance is indicator of low temperature. Before compaction mat temperature should be checked for mat thickness. During cold weather tarpaulin was used in M2 to avoid heat loss

CHAPTER 5

FINDINGS/CONCLUSIONS

5.1 Findings

From literature review, survey responses and expert opinions (field / academic) following are the findings of the research work:-

a. There are 10 main factors which affects the quality of rehabilitation of the pavements

b. 98 sub factors were identified for good rehabilitation of pavement

c. Main and supporting activities of the rehabilitation of the pavements are interrelated with one another

d. Order of priority comes out for main factors affecting the quality of rehabilitation of pavement is as under

   (1). Good paving practices

   (2). Good compaction practices

   (3). Effective drainage system

   (4). Prime / tack coat (execution / application)

   (5). Transportation of material within suitable temperatures

   (6). Brooming / cleanliness standard

   (7). Execution of joints

   (8). Appropriate crack repair / patching of milled surface

   (9). Appropriate milling methodology

   (10). Fulfillment of road opening requirements

e. Formulation of a checklist for field staff is necessitated.

f. Gap between theoretical knowledge and practical execution exists.

g. State of the art machinery & plant with automation systems brought great dividends to quality.

h. National level rehabilitation projects are great opportunity for learning of academic & field staff.

i. Innovations should not be discouraged to keep the window of agitation open.

j. Adherence to identified factors and sub factors during execution is a must.

k. Students of highway and transportation engineering should be provided with requisite data for further investigations and refinements in execution of rehabilitation projects.

5.2 CONCLUSIONS

a. Identification of important factors / sub factors enable us to identify the critical activities which need special emphasis during execution.

b. Priority of factors & sub factors dictates the selection of activities among all the activities being executed in a particular time frame.

c. This research enable us to prepare a check list for guidance & inspection of the quality of execution of rehabilitation activities.

d Good paving practices, good compaction and effective drainage systems emerges as most important activities of rehabilitation.

e Attaining of good IRI, field density and timely placing of HMA appeared as important sub factors for achieving well laid & compacted HMA.

f Induction of all available automatic plant machinery and equipment is demand of the time. It will ensure improvement in quality & avoidance of human error.

g. Mere theoretical knowledge of Engineering practices and only field experience without the knowledge of latest practices in vogue will not bring commendable contribution in quality of execution of rehabilitation.

h. In some of the cases innovative ideas can also bring a useful contribution for quality maintenance

i. Operational administration will enable to complete the deficiency of requisite equipment for quality improvement.

j. Compromise on quality in execution of rehabilitation will bring early maintenance followed by premature completion of rehabilitation design life.

k. Rehabilitation of M2 provided a golden opportunity to the Transportation Engineering students for research work.

5.3 RECOMMENDATIONS

a. Identification of factors and sub factors for rehabilitation of pavements was formulated by trinity of effort through literature review, field visits and questionnaire survey. Formulation of execution methodology from these factors and sub factors should be carried out for improved execution of rehabilitation in future.

b. All rehabilitation activities should be directed towards the achieving of good paving/ compaction practices, effective drainage system, IRI, requisite field density and timely placing of HMA.

c. Induction of state of the plant machinery & equipment will resolve the issues of accurate quantities as well as of quality.

d. Academia & field staff should proceed hand in hand for collaborated efforts of quality assurance. Publication of quality related manuals in Urdu / English for field staff should be the first step towards this end.

e. Centralized data collection center may be established at NHA level for collection and updating of the data of pavement rehabilitation projects.

f. Future studies for ranking and quantification of these factors & sub factors may be carried out.

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Anx 'A'

QUALITY IN EXECUTION OF REHABILITATION OF PAVEMENTS

In order to improve the quality of rehabilitation of pavements, a survey is being conducted. Your valuable contribution will a go long way in establishing bench mark for good engineering practices, specially in rehabilitation of motorways / highways in Pakistan.

Demographic Data			
Following data is being compiled for academic purposes only. Personal information will not be shared.			
Name:		**Age:**	
Highest Qualification:		**Experience in road construction / rehabilitation : __Yrs**	
Sector: Public_____ Private_____			
Company / Organization		**Appointment:**	
Organizational Measures			
	Have you received formal quality training?	**Yes**	**No**
	Does your company have a formal quality program?	**Yes**	**No**
	Is this quality program effective?	**Yes**	**No**
	Is there any quality record mechanism in your organization ?	**Yes**	**No**
	Does your company have a separate quality department?	**Yes**	**No**
	Is quality training provided to new workers?	**Yes**	**No**
	Is the quality policy displayed?	**Yes**	**No**
	Does your company employ a full time quality officer on site?	**Yes**	**No**

	Who is responsible to ensure quality on site? a. **Consultant** b. **Site Engineers** . **Project Manager** d. **Local Agencies. contractor** f. **Other**		
	Is the cost of quality included in your contract price? If yes then what percentage of contract price is it?	**Yes------%**	**No**
1	How frequently you carry out quality meetings on site? a. Weekly b. Fortnightly c. Monthly d. Never		
2	Has your site ever been visited by a government official for quality inspection?	**Yes**	**No**
3	Does your company maintain record of expenses incurred on quality?	**Yes**	**NO**

EVALUATION OF FACTORS / SUB FACTORS FOR QUALITY INEXECUTION OF REHABILITATION OF PAVEMENTS

Prime contributors to quality of execution in rehabilitation of surface course / pavement of Motorways / highways are appended below. Kindly give them weightage from 1-5 basing of their relative importance as mentioned below; -

1. Irrelevant **2. Not so important** **3. Important to some extent**

4. Significant **5. Extremely important**

S/No	**Sub Factors**	**score based on significance**				
		1	**2**	**3**	**4**	**5**
1.	Milling Methodology					
2.	Surface Drainage System					
3.	Crack repair/patching of milled surface					
4.	Brooming / cleanliness Standard					
5.	Prime / Tack coat (execution / application)					

6.	Transportation of Material within suitable temperatures					
7.	Good paving practices					
8.	Good Compaction Practices					
9.	Execution of Joints in Rehabilitation of pavements					
10.	Fulfillment of road opening requirements					

Irrespective of the weightage given to the above factors. How much weightage you will give to following sub factors of the a/m factors.

S/No	**1. SUBFACTORS FOR MILLING METHODOLOGY**	**Score**				
		1	**2**	**3**	**4**	**5**
1.	Speed of milling machine / drum					
2.	Depth of milling					
3.	Use of several sensors with milling machine including grade sensors					
4.	Disposal of milled material away from work zone					
5.	Proficiency level of surveyor / operator					
6.	Cleanliness of the milled surface					
7.	Straightening of edges of adjacent un milled pavement					
8.	Use of straight edge equipment					
9.	Milling surface inspection to see difference as compare to profile level					

S/No	**2. SUBFACTORS SURFACE DRAINAGE SYSTEM**	**Score**				
		1	**2**	**3**	**4**	**5**
1.	cutting of temporary drainage channels in shoulders					

2.	Drainage channels depth as same as milling depth					
3.	Suitable spacing in between drainage channels/catch pits					
4.	Drainage outlet ditches for protection works during construction					
5.	Cleaning of the existing drainage system					
6.	Redressal of Design faults / already existing faults					
7.	Maintenance of design x slope for surface runoff					

S/No	**3. SUBFACTORS FOR CRACK REPAIR/ PATCHING OF MILLED SURFACE**	**Score**				
		1	**2**	**3**	**4**	**5**
1.	Cutting / Grooving method (asphalt cutter, small milling machine or jack hammer)					
2.	Sealing of minor cracks / patch edges					
3.	Cleaning and drying of grooved cracks					
4.	Milling of cracked area if cracks > (6-12) in 25-50 m area					
5.	Chamfering of sharp edges					
6.	Tack coat application					
7.	Filling up of the cracks with paver if they are in abundance					
8.	Maximum lift thickness should not be more than 4 inches					
9.	Compaction of each lift					
10.	¼ ‘’extension of final un compacted lift above the surrounding pavement					

S/No	**4. SUBFACTORS FOR BROOMING/ CLEANLINESS**	**Score**				
		1	**2**	**3**	**4**	**5**
1.	Proper use of the equipment					
2.	Use of hand brooms for leftover of air compressor					

3.	Cleanliness of milled surface from loose material, dust, droppings and residuals					
4.	Dryness of the surface					
5.	Brooming before every prime / tack coat application					

S/No	**5.SUBFACTORS FOR PRIME / TACK COAT APPLICATION**	**Score**				
		1	**2**	**3**	**4**	**5**
1.	Surface cleanliness / preparation					
2.	Suitable Method of application (hand pump / pressure distributer)					
3.	Quality of material (bituflex / RC 250 asphalt)					
4.	Uniform distribution of asphaltic liquid					
5.	Spreading of sand etc. to prevent picking up wheels of traffic					
6.	Control / Accuracy on Rate of application					
7.	Suitable rest or curing time (of 24 hours) after prime coat					
8.	Non tacky condition of prime coat before asphaltic operation					
9.	Proper curing of Primed Base					
10.	Application of next course within tackiness condition of tack coat					
11.	Requirement / application of tack coat on vertical faces of joints					

S/No	**7.SUBFACTORS FOR TRANSPORTATION OF MATERIAL Factors**	**Score**				
		1	**2**	**3**	**4**	**5**
1.	Constant supply of HMA from plant to site					
2.	Visual inspection and test of asphalt mixture					
3.	Compatibility of size paver vis a vis truck					

4.	Bed of dumper should be free from debris or residual of previous supply					
5.	Coating of truck bed with release agent					
6.	Adherence to the requisite temperature of HMA while loading , unloading / laying and compaction					
7.	Avoidance of segregation and lumps					
8.	Allowing load to break before tailgate is opened					

S/No	**8. SUBFACTORS FOR PAVING PRACTICES**	**Score**				
		1	**2**	**3**	**4**	**5**
1.	Removal / dryness of rainwater etc. prior to laying of HMA					
2.	Visual inspection of HMA					
3.	Use of appropriate method for achieving design profile					
4.	Keeping the hopper filled up with HMA all the time during laying operation					
5.	Consistency of the head of material in front of the screed					
6.	Setting of paver with appropriate compaction, cross slope and vibration					
7.	Setting of pavement screed for initial compaction and shape of the surface					
8.	Placing of HMA before heat loss					
9.	Consistency in layer thickness					
10.	Simultaneous laying of all lanes on one side of median to avoid cold joints					
11.	Spreading of mix according to established grade , elevation and slope with paver					
12.	Bumping of paver to avoid production of hump					
13.	Use of automatic screed control					

S/No	9. SUBFACTORS FOR COMPACTION PRACTICES	Score				
		1	2	3	4	5
1.	Uniform / slow speed of the tandem rollers/PTR					
2.	Adherence to pattern / sequence of compaction					
3.	Adherence to initial and breakdown rolling temperature					
4.	Avoidance of backlash while using rollers in reverse direction					
5.	Overlapping of successive trips					
6.	Requisite contact pressure for compaction					
7.	Recommended air pressure in pneumatic tyres of paver group					
8.	Lubricating of PTR wheels with release agent					
9.	Moistening of roller wheels to prevent adhesion					
10.	Avoidance of skin patching					
11.	Maintenance of Asphaltic course thickness					
12.	Minimizing of transverse joint					
13.	Secondary or intermediate rolling with PTR					
14.	Achieving of 97 - 98% of laboratory compaction / martial density					
15.	Finish rolling to remove roller marks before cession temperature					
16.	After compaction checking of pavement smoothness with straight edge					
17.	Continuous monitoring of time and duration of rolling					

S/No	9. SUBFACTORS FOR EXECUTION OF JOINTS IN REHABILITATION OF PAVEMENTS	Score				
		1	2	3	4	5
1.	Cleanliness of dust					
2.	Cutting of edges by cutters					
3.	Application of Tack coat on vertical face of cold joint					
4.	Staggering of transverse joints of consecutive layers					
5.	Overlapping					

6.	Absence of bump					
7.	Use of two pavers parallel in hot joints					
8.	Matching of thickness, density and uniformity in two mats of hot joint					
9.	Meeting of Second overlay with previously placed pavement in depth, grade and slope in cold joints					
10.	Cutting of longitudinal edge up to full depth in cold joints					
11.	Cutting of longitudinal edge 75 mm to 100 mm from the joint					
12.	Offsetting of longitudinal joint of lower layer from upper layer					

S/No	**10. SUBFACTORS FOR FULLFILMENT OF ROAD OPENING REQUIREMENTS**	**Score**				
		1	**2**	**3**	**4**	**5**
1.	IRI should be < or = 1.5					
2.	Opening of fresh treated road at control speed for traffic					
3.	Minimum rest period of 24 hours					
4.	Grinding of high spots, if any					
5.	Visual survey to view the condition of freshly compacted surface					
6.	Absence of longitudinal as well as transverse undulations					
7.	Cooling of full depth of HMA to 40 degree C					

Comments /suggestions ----------

Thanks for your valuable time.

Anx 'B'

CHECK LIST

Following should be kept in mind while using this check list :-

a. Machineries and equipment is available in well maintained condition. It is being certified by the competent authorities at regular intervals. Hence, machinery and equipment is in ideal working condition.

b. Base and sub-base layers does not have structural / functional feature.

c. Shoulders don't need rehabilitation.

d. Since it is rehabilitation work so there is no issue/concern regarding survey and geometrics of the road.

e. There is no issue of availability of manpower. However, competency/ experience of the labour is variable.

f. All material is of good quality.

g. Drawings / design and JMF have been approved by the consultants.

h. Relevant tests / inspections are being performed regularly.

i. Transportation/ storage facilities and practices for raw materials are ideal.

j. All safety requirements are known and are adhered to.

k. Weather conditions and working hours are in accordance with the working environment.

1. MILLING METHODOLOGY

S/No	Inspection Points	Remarks
1.	Speed of milling machine / drum	
2.	Depth of milling in one go	
3.	Use of several sensors with milling machine including grade sensors	
4.	Disposal of milled material away from work zone	
5.	Proficiency level of surveyor / operator	
6.	Cleanliness of the milled surface	
7.	Straightening of edges of adjacent un milled pavement	
8.	Use of straight edge equipment	

9.	Milling surface checking to see the difference as compare to profile level (use of profile meter)	
10.	Any other point / observations ---------- ---------- ----------	

2. SURFACE DRAINAGE SYSTEM

S/No	Inspection Points	Remarks
1.	Milling of driving lane and shoulders on same day for drainage	
2.	Drainage of un-milled lanes	
3.	cutting of temporary drainage channels in shoulders	
4.	Drainage channels depth as same / lower as compare to milling depth	
5.	Suitable spacing in between drainage channels/catch pits	
6.	Drainage outlet ditches for protection works during construction	
7.	Cleaning of the existing drainage system	
8.	Provision of French drainage as weep holes	
9.	Redressal of Design faults / already existing faults	
10.	Maintenance of design x slope for surface runoff	
11.	Any other point / observations ---------- ----------	

3. CRACK REPAIR/ PATCHING OF MILLED SURFACE

S/No	Inspection Points	Remarks
1.	Appropriate Cutting / Grooving method as per nature of crack (asphalt cutter, small milling machine or jackhammer)	
2.	Sealing of minor cracks / patch edges	
3.	Use of appropriate method of crack repair	
4.	Cleaning and drying of grooved cracks	
5.	Milling of cracked area if cracks > (6-12) in 25-50 m area	

6.	Chamfering of sharp edges	
7.	Tack coat application	
8.	Filling up of the cracks with paver if they are in abundance	
9.	Maximum lift thickness should not be more than 4 inches	
10.	Compaction of each lift	
11.	¼ '' extension of final un compacted lift above the surrounding pavement	
12.	Removal of loose material down to a solid base	
13.	Use of straight edge to check the level	
14.	Day to day inspection of cracks / treatments	
15.	Any other point / observations ---------- ----------	

4. BROOMING/ CLEANLINESS STANDARD

S/No	Inspection Points	Remarks
1.	Appropriate size and use of brooming machine	
2.	Use of appropriate type of brooming	
3.	Use of compressed air	
4.	Proper use of the equipment	
5.	Use of hand brooms for leftover of air compressor	
6.	Cleanliness of milled surface from loose material, dust, droppings and residuals	
7.	Dryness of the surface	
8.	Brooming before every prime/ tack coat application	
9.	Any other point / observations ---------- ----------	

5. PRIME / TACK COAT (EXECUTION / APPLICATION)

S/No	Inspection Points	Remarks
1.	Surface cleanliness / preparation	
2.	Dryness of the previous application, if any	
3.	Method of application (hand pump / pressure distributer)	

4.	Quality of material (bit flex / RC 250 asphalt)	
5.	Uniform distribution of asphaltic liquid	
6.	Spreading of sand etc. to prevent picking up wheels of traffic	
7.	Control / Accuracy on Rate of application	
8.	Suitable rest or curing time (of 24 hours) after prime coat	
9.	Non-tacky condition of prime coat before asphaltic operation	
10.	Proper curing of Primed Base	
11.	Avoidance of unnecessary Movement of trucks after application of tack coat	
12.	Application of next course within tackiness condition of tack coat	
13.	Requirement / application of tack coat on vertical faces of joints	
14.	Adherence to the ratio between bitumen and kerosene oil / petrol for prime coat and tack coat respectively	
15.	Any other point / observations ---------- ----------	

6. TRANSPORTATION OF MATERIAL

S/No	Inspection Points	Remarks
1.	Constant supply of HMA from plant to site	
2.	Visual inspection and test of asphalt mixture	
3.	Compatibility of size paver vis a vis truck	
4.	Avoidance of stickiness of HMA to the bed	
5.	Bed of dumper should be free from debris or residual of previous supply	
6.	Coating of truck bed with release agent	
7.	Adherence to the requisite temperature of HMA while loading, unloading / laying and compaction	
8.	Avoidance of segregation and lumps	
9.	Allowing load to break before tailgate is opened	
10.	Use of tarpaulin to avoid heat loss of HMA	
11.	Any other point / observations ---------- ----------	

7. PAVING PRACTICES

S/No	Inspection Points	Remarks
1.	Removal / dryness of rainwater etc. prior to laying of HMA	
2.	Visual inspection of HMA	
3.	Use of appropriate method for achieving design profile	
4.	Keeping the hopper filled up with HMA all the time during laying operation	
5.	Consistency of the head of material in front of the screed	
6.	Setting of pavers with appropriate compaction, cross slope and vibration	
7.	Setting of pavement screed for initial compaction and shape of the surface	
8.	Placing of HMA before heat loss	
9.	Consistency in layer thickness	

10.	Simultaneous laying of all lanes on one side of median to avoid cold joints	
11.	Paving of inner lane in earlier time frame	
12.	Spreading of mix according to established grade, elevation and slope with paver	
13.	Bumping of paver to avoid production of hump	
14.	Use of automatic screed control	
15.	Continuous movement of paver with constant speed	
16.	Any other point / observations ---------- ---------- ----------	

8. COMPACTION PRACTICES

S/No	Inspection Points	Remarks
1.	Appropriate size /weight of the roller /PTR	
2.	Uniform / slow speed of the tandem rollers/PTR	
3.	Adherence to pattern / sequence of compaction	
4.	Adherence to initial and breakdown rolling temperature	
5.	Beginning of rolling from lower side of the spread	
6.	Avoidance of backlash while using rollers in reverse direction	
7.	Overlapping of successive trips	
8.	Requisite contact pressure for compaction	
9.	Recommended air pressure in pneumatic tyres of paver group	
10.	Lubricating of PTR wheels with release agent	
11.	Moistening of roller wheels to prevent adhesion	
12.	Avoidance of skin patching	
13.	Maintenance of Asphaltic course thickness	
14.	Minimizing of transverse joint	
15.	Secondary or intermediate rolling with PTR	

16.	Achieving of 97 - 98% of laboratory compaction / martial density	
17.	Finish rolling to remove roller marks before cession temperature	
18.	After compaction checking of pavement smoothness with straight edge	
19.	Continuous monitoring of time and duration of rolling	
20.	Any other point / observations ---------- ---------- ---------- -	

9.EXECUTION OF JOINTS IN REHABILITATION OF PAVEMENTS

S/No	Inspection Points	Remarks
1.	Cleanliness of dust	
2.	Cutting of edges by cutters	
3.	Tack coat on vertical face of joint if second pavement is placed after 72 hours	
4.	Placing of timber/angle iron for verticality of the joint	
5.	Staggering of transverse joints of consecutive layers	
6.	Overlapping	
7.	Absence of bump	
8.	Use of two pavers parallel in hot joints	
9.	Use of straight edge while laying construction joints	
10.	Matching of thickness, density and uniformity in two mats of hot joint	
11.	Meeting of Second overlay with previously placed pavement in depth, grade and slope in cold joints	
12.	Cutting of longitudinal edge up to full depth in cold joints	
13.	Cutting of longitudinal edge 75 mm to 100 mm from the joint	

14.	6 inches ride of roller on already existing lane in longitudinal cold joints	
15.	Offsetting of longitudinal joint of lower layer from upper layer	
16.	Any other point / observations ---------- ----------	

10. FULLFILMENT OF ROAD OPENING REQUIREMENTS

S/No	Inspection Points	Remarks
1.	IRI should be < or = 1.5	
2.	Opening of fresh treated road at control speed for traffic	
3.	Minimum rest period of 24 hours	
4.	Quality	
5.	Visual survey to view the condition of freshly compacted surface	
6.	Absence of longitudinal as well as transverse undulations	
7.	Grinding of the high spots/Undulations , if any	
8.	Cooling of full depth of HMA to 40 degree C	
9.	Any other point / observations ---------- ----------	