Development of a Systematic Approach for Sustainable Maintenance Management System for Road Network in India

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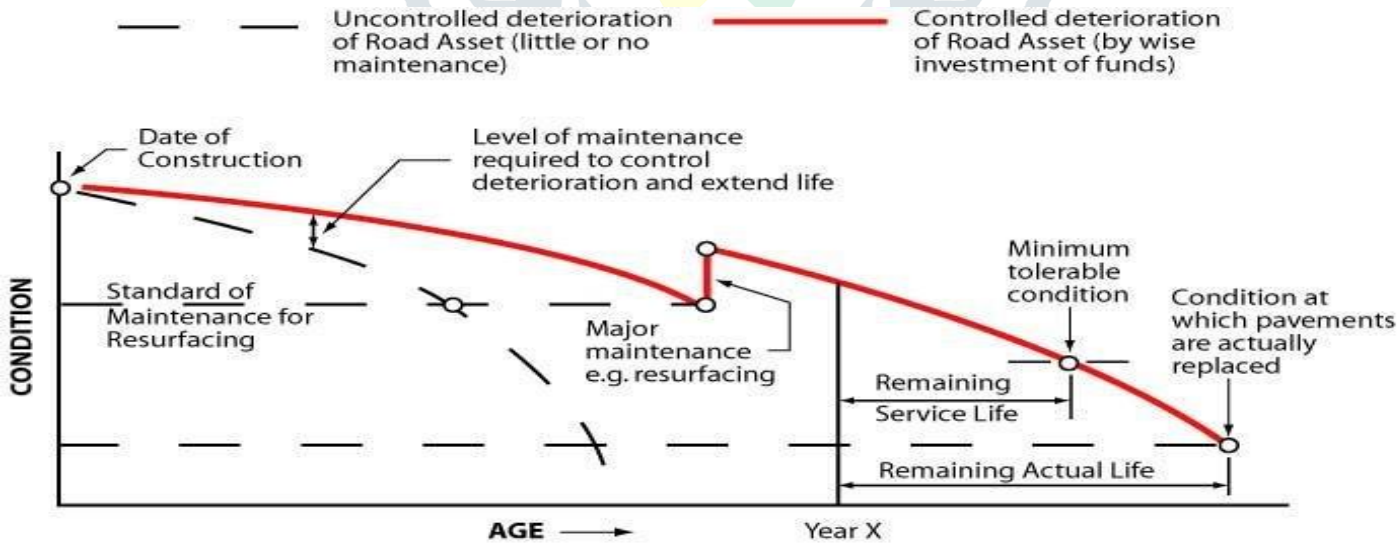
Abstract : Highway plays a crucial role in the economic and social development of societies, linking rural communities to education, health services and markets. Highways are deteriorating fast due to lack of timely maintenance, leading to higher vehicle operating costs, increasing number of accidents. Huge resources are being spent on the maintenance and development of existing roadways in India to ensure the mobility of people and goods. In this study a rational methodology to allocate resources for different maintenance activities to be carried out on different sections in a road network is proposed. The maintenance priority is based on importance of the road sections, present road conditions, and future road conditions. The methodology proposed in this study is validated by considering the real road network in Vidisha city in the state of Madhya Pradesh. A analysis is carried out to assess the impacts of input parameters in the performance of developed methodology. Three different levels of funds available i.e. 25 %, 50 % and 75 % is considered and results were compared to assess the suitability of the proposed methodology. As a result of the research an adaptable and adoptable sustainable maintenance management system for rural networks is developed to assist local road agencies in developing countries. It is expected that this study will be useful.

IndexTerms **- Maintenance priority, Sustainable management, Rational methodology, Maintenance Management, Resources.**

I. INTRODUCTION

Highway plays a crucial role in the economic and social development of societies, linking rural communities to education, health services and markets. A huge road network constructed recently in developing countries has resulted in increased social and economic benefits. However, these benefits would reduce substantially due to poor maintenance of the constructed roads. Thus, in order to reap the benefits of created assets it is essential to maintain the roads timely.

However, increasing traffic loading, deteriorating road conditions, and shrinking resources have presented a complex situation in maintenance aspect. Huge resources are being spent on the maintenance and development of existing roadways in India to ensure the mobility of people and goods. In this thesis a rational methodology to allocate recourses for different maintenance activities to be carried out on different sections in a road network is proposed. The maintenance priority is determined on the basis of present and future condition of the highway sections as well as importance of the sections. It is expected that this study will be useful for maintenance of huge highway network in India and thus will be useful for preserving the huge investments made in developing such a highway network in India.



II. METHODOLOGY FOR RESOURCE ALLOCATION

The main objective of this study is to develop a methodology to allocate resources for maintenance of a highway network in India. As discussed earlier, to utilize the limited resources rationally, there is a need to allocate these resources considering the priority of different maintenance activities to be carried out on different sections in a highway network. The methodology allocates the resources considering the maintenance priorities of different activities to be carried out. The maintenance priority is determined on the basis of present conditions, future condition as well as importance of the different highway sections in the network. It is proposed to determine priority index of maintenance activity to be carried out on section S (PI_{as}) as given in Equation 1 as follows:

$$PI_{as} = [\{(PDSI)_s W_{adc} W_{dc} W_s\} + \{(PDTSI)_s W_{adc} W_{dc} W_s\} + \{(PDISI)_s W_{adc} W_{dc} W_s\} + \{(PSCI)_s W_{adc} W_{dc} W_s\}] + [\{(FFSI)_s W_{adc} W_{dc} W_s\} + \{(FDTSI)_s W_{adc} W_{dc} W_s\} + \{(FDISI)_s W_{adc} W_{dc} W_s\} + \{(FSCI)_s W_{adc} W_{dc} W_s\}] \quad \ldots\ldots (Eq.1)$$

where,

PIas - Priority of maintenance activities to be carried out on section S
PDSIs - Present Distress Condition index at section S
PDTSIs - Present Distorted Condition index at section S
PDISIs - Present Disintegrated Condition index at section S
PSCIs - Present Structural Condition index at section S
FDSIs - Future Distress Condition index at section S
FDTSIs - Future Distorted Condition index at section S
FDISIs - Future Disintegrated Condition index at section S
FSCIs - Future Structural Condition index at section S
Wadc - Weightage of activity (a) in improving distress condition
Wdc - Weightage of distress condition
Ws - Weightage of Section S

2.1 - Major Steps Involved in methodology

The major steps involved for proposed methodology for resource allocation for highway maintenance are briefly explained as follows:

Step 1: Determination of Present Highway Condition Indices

In the first step, various present highway condition indices needs to be determined based on present road distress condition data for all the sections. Table -1 explains how to determine these present road condition indices.

TABLE I
TABLE 1: DETERMINATION OF PRESENT ROAD CONDITION INDICES

PDSI =	(Present Factured area(in percentage of total area)on the section) / (Maximum fractured area in percent of total area on any section in the network)
PDTSI=	(Present Distorted area(in percentage of total area)on the section)/(Maximum Distorted area in percent of total area on any section in the network)
PDISI=	(Present Disintergrated area(in percentage of total area)on the section)/(Maximum Disintergrated area in percent of total area on any section in the network)

Step 2: Prediction of Future Highway Condition Indices

In the second step, various future highway condition indices needs to be determined based on future highway distress condition data for all the sections Table -2 explains how to determine these future road condition indices.

TABLE III
TABLE 1: DETERMINATION OF FUTURE ROAD CONDITION INDICES

FFSI=	(Future Factured area(in percentage of total area)on the section)/(Maximum fractured area in percent of total area on any section in the network)
FDTSI=	(Future Distorted area(in percentage of total area)on the section)/(Maximum Distorted area in percent of total area on any section in the network)
FDTSI=	(Future Disintegrated area(in percentage of total area)on the section)/(Maximum Disintegrated area in percent of total area on any section in the network)

Future highway condition indices are determined using Future fractured area, Future distorted area, and Future disintegrated area which can be determined using appropriate distress propagation models. Details of such models are given elsewhere.

Step 3: Determination of Different Weightage

In step 3 the different weightage i.e.W_s, W_{dc}, W_{adc} need to be determined. These weightage are determined considering their relative importance in improving the highway conditions and importance of the sections etc. Typical values as suggested in literature (Das, 2010; Agarwal, 2006) can be adopted for analysis and determination of priority of various maintenance activities to be carried out at different sections.

Step 4: Determination of Priority Index

In Step 4, priority index of activity a to be carried out at section S (i.e. PI_{aS}) needs to be determined for all the activities at all the sections in the highway network. PI_{aS} for various maintenance activities can be determined using the Equation 1 as given above.

Step 5: Allocation of Resources for highway maintenance

In the last step, resources are allocated on the basis of Priority Index (as obtained in step 4) of different maintenance activities.

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III. Analysis And Result Using Proposed Methodology

This section of the study presents analysis and results for the proposed methodology to illustrate, how the proposed methodology works for development of a systematic approach for sustainable maintenance management system for road network in India. To illustrate how methodology works, the following two cases were analyzed. CASE I: Resource allocation based on priority Index i.e on the basis of the methodology proposed in this study. CASE II: Resource allocation based on present practice i.e based on the overall importance of the section.

To illustrate, how the proposed methodology works, a case study of a real road network of Vidisha city of Madhya Pradesh consisting of four important road sections is considered. The input data were collected from the some field survey works and from different road authority like NHAI, CPWD, PWD and Nagar Palika (Vidisha).

Table I presents the details of the sections considered i.e. length, width, classification of highway, connected places, political importance etc. Details of present distresses on various road sections considered are given in Table II. The details of various maintenance activities required are given in Table III. The various resources required to carry out various maintenance activities are funds, equipment (like paver, roller, hot mix plant etc.), manpower (i.e labour, supervisor etc.), material (i.e. aggregates, bitumen, emulsion, cement etc.). However, availability of the fund is the most important resources. Hence, in this study only funds constraint is considered. The amount required for various maintenance activities are calculated on the basis of quantity of the work required and that is multiplied by the rate of the item. The rates are taken on the basis schedule of rate of MPRRDA and PWD, March, 2019.

TABLE IIIII
INPUT DATA: DETAILS OF THE HIGHWAY SECTIONS FOR THE CASE STUDY CONSIDERED

S.No.	Section Name Designation	Length (m)	Width (m)	Road Classification	Important places connected	Political Importance
1	S_1 (From Railway station Platform no.1 to Din Dayal Upadhyaya junction)	1000	7	Major Arterial Road	Railway Station, Hospitals, Market, Hotels	High
2	S2 (Durganagr Square to Durga nagar)	1200	7	Local Street	Residential, Market, Indian Bank	Low
3	S3 (Durganagar Square to Railway station (Platform no. 4)	500	7	Local Street	Railway Station , Market, Restaurant	Medium
4	S4 (From Ahemadpur Square to Vidisha District Court (Infront of SATI College)	1500	7	Major Arterial Road	College, Market , Railway Station and Vidisha District Court	High

The details of distress area of different selected road section are shown in Table IV.

TABLE IV
INPUT DATA: DETAILS OF DISTRESSES OF VARIOUS ROAD SECTIONS

Sections	PFS	PDTS	PDIS	PSC	FFS	FDTS	FDIS	FSC
	m^2	m^2	m^2	mm	m^2	m^2	m^2	
S1	280	140	420	**0.50**	795	200	721	**0.73**
S2	252	189	504	**0.60**	834	252	1023	**0.88**
S3	1575	80	1330	**1.90**	2961	112	3080	**4.1**
S4	1190	1260	1680	**1.85**	3150	3010	4095	**2.06**

The details of the distress conditions present and maintenance activity required on various section is shown in Table V.

TABLE V
INPUT DATA: DETAILS OF THE DISTRESS CONDITIONS PRESENT AND MAINTENANCE ACTIVITIES REQUIRED ON THE VARIOUS SECTIONS (CASE I)

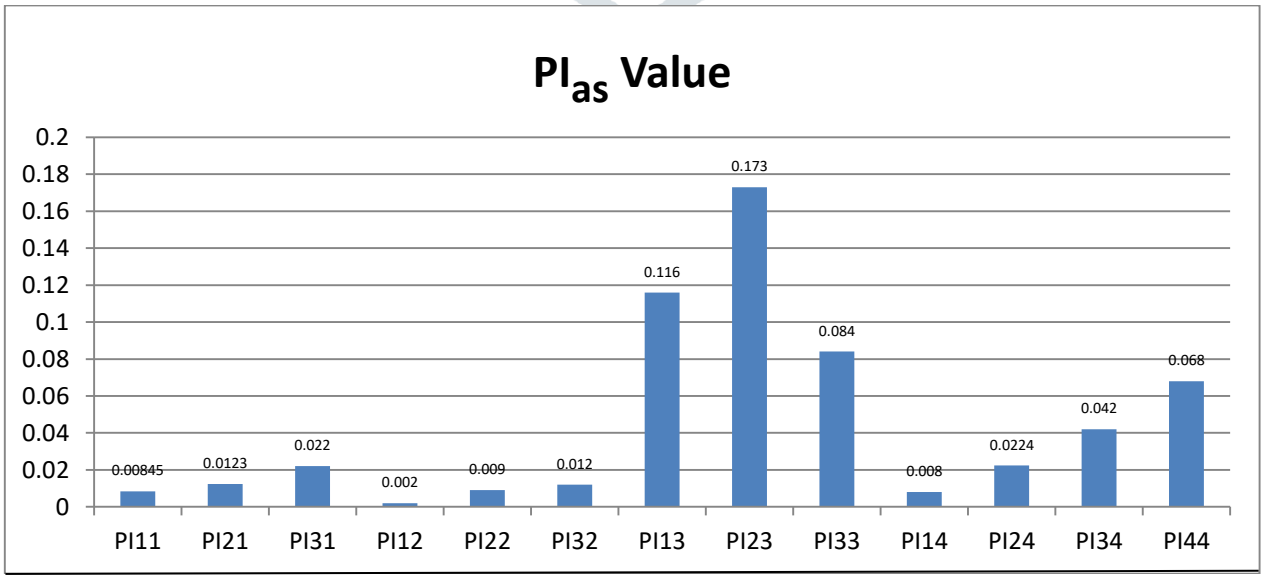
Section	Distresses	Required Activities	Designation
S_1	Fractured Surface(Cracks) Disintegrated Surface (Pot holes) Distorted surface(Rutting)	Filling Patching Patching	A11 A12 A13
S_2	Fractured Surface(Cracks) Disintegrated Surface (Pot holes) Structural defect	Filling Patching Overlay	A21 A22 A23
S_3	Fractured Surface (Cracks) Disintegrated Surface (Pot holes) Distorted Surface(Rutting)	Filling Patching Patching	A31 A32 A33
S4	Fractured Surface (Cracks) Distorted surface(Rutting) Disintegrated Surface (Pot holes) Structural defect	Filling Patching Patching Overlay	A41 A42 A43 A44

Further, after calculating the present and future indices the details of calculated Priority Index (PI as) of activities on different identified sections (S) are shown in table VI below:

TABLE VI
RESULT: PRIORITY & RANKING BASED ON THE CALCULATED VALUE OF PI_{as}

Road Sections	Activities	PIas	PIas Value	Rank
S_1	A_{11}	PI_{11}	0.00845	11
	A_{12}	PI_{21}	0.0123	8
	A_{13}	PI_{31}	0.022	7
S_2	A_{21}	PI_{12}	0.002	13
	A_{22}	PI_{22}	0.009	10
	A_{23}	PI_{32}	0.012	9
S_3	A_{31}	PI_{13}	0.116	2
	A_{32}	PI_{23}	0.173	1
	A_{33}	PI_{33}	0.084	3
S_4	A_{41}	PI_{14}	0.008	12
	A_{42}	PI_{24}	0.0224	6
	A_{43}	PI_{34}	0.042	5
	A_{44}	PI_{44}	0.068	4

The results of Section Ranking on the basis of calculated Priority index value are graphically presented in Figure below.



The various resources required to carry out various maintenance activities are funds, equipment (like paver, roller, hot mix plant etc.), manpower (i.e. labour, supervisor etc.), material (i.e. aggregates, bitumen, emulsion, cement etc.). However, availability of the fund is the

most important resources. Hence, in this study only funds constraint is considered.The amount required for various maintenance activities are calculated on the basis of quantity of the work required and that is multiplied by the rate of the item. The rates are taken on the basis schedule of rate of MPRRDA and PWD, March, 2019. The various maintenance activities considered and their rates are given in Table.VII

TABLE VII
RESULT: DETAILS OF RESOURCE (FUND) REQUIRED FOR VARIOUS MAINTENANCE ACTIVITIES

Road Sections	Activities	PIas	PIas Value	Rank	Maintenance cost(rates)
S_1	A_{11}	PI_{11}	0.00845	11	56520.00
	A_{12}	PI_{21}	0.0123	8	45780.0
	A_{13}	PI_{31}	0.022	7	78780.0
S_2	A_{21}	PI_{12}	0.002	13	55061.0
	A_{22}	PI_{22}	0.009	10	53702.0
	A_{23}	PI_{32}	0.012	9	89237.0
S_3	A_{31}	PI_{13}	0.116	2	340536.0
	A_{32}	PI_{23}	0.173	1	373390.0
	A_{33}	PI_{33}	0.008	3	3461440.0
S_4	A_{41}	PI_{14}	0.008	12	276210.0
	A_{42}	PI_{24}	0.0224	6	276020.0
	A_{43}	PI_{34}	0.042	5	43246.0
	A_{44}	PI_{44}	0.068	4	2056800.0
Total maintenance Cost Required is Rs.7206722					

The details of identified road sections on the basis of their importance and maintenance activities are shown in table 8 below.

TABLE VIII
RESULT: DETAILS OF SECTION (IN THE ORDER OF THEIR IMPORTANCE) AND MAINTENANCE ACTIVITIES TO BE CARRIED OUT

Road Sections	Activities	Rank	Maintenance cost(rates)
S_1 (Overall importance of the section Ws= 0.87)	A_{11}	11	56520.00
	A_{12}	8	45780.0
	A_{13}	7	78780.0
S_2 (Overall importance of the section Ws= 0.86)	A_{21}	13	55061.0
	A_{22}	10	53702.0
	A_{23}	9	89237.0
S_3 (Overall importance of the section Ws= 0.17)	A_{31}	2	340536.0
	A_{32}	1	373390.0
	A_{33}	3	3461440.0
S_4 (Overall importance of the section Ws= 0.16)	A_{41}	12	276210.0
	A_{42}	6	276020.0
	A_{43}	5	43246.0
	A_{44}	4	2056800.0

Comparison of the proposed Methodology

The methodology proposed in this study is illustrated with the help of an example of a small real highway network of Vidisha city (M.P) considering of 4 sections. Three different level of funds available i.e 25 %, 50 % and 75 % is considered and results were compared to assess the suitability of the proposed methodology. The results obtained using proposed methodology is compared with the practice of resource allocation on ad-hoc basis (i.e. resources are allocated to more important sections first). The comparison clearly illustrates that the methodology proposed in this study allocates the limited resources more rationally.

The results obtained for resource allocation for case-IA (When 25 % Budget Available) is presented in Table VII

TABLE VII
ANALYSIS AND RESULT FOR RESOURCES ALLOCATION (CASE – I A) CASE-I A = WHEN 25% BUDGET AVAILABLE

Resources Allocation Based on Proposed Methodology (Priority Index)				
S.NO	**Section**	**Activity**	**Designation**	**Fund Allocated (Rs.)**
1	S_3	Patching (Pothole)	A_{32}	73390.0
2	S_1	Patching (Pothole)	A_{13}	78780.0
3	S_1	Patching (Rutting)	A_{12}	45780.0
4	S_3	Crack (Filling)	A_{31}	340536.0
5	S_2	Patching (Pothole)	A_{32}	373390.0
6	S_4	Patching (Rutting)	A_{42}	276020.0
7	S_1	Crack (Filling)	A_{11}	56520.00
8	S_4	Crack (Filling)	A_{41}	276210.0
9	S_2	Patching (Rutting)	A_{22}	53702.0
10	S_2	Crack (Filling)	A_{21}	55061.0

Resources Allocation Based on Present Practices (Importance of Section)\				
S.NO	**Section**	**Activity**	**Designation**	**Fund Allocated (Rs.)**
1	S_1	Crack (Filling)	A_{11}	56520.00
2	S_1	Patching (Pot hole)	A_{12}	45780.0
3	S_1	Patching (Rutting)	A_{13}	78780.0
4	S_3	Crack (Filling)	A_{31}	340536.0
5	S_3	Patching (Pot hole)	A_{32}	373390.0
6	S_2	Crack (Filling)	A_{21}	55061.0
7	S_2	Patching (Pot hole)	A_{22}	53702.0
8	S_2	Patching (Rutting)	A_{23}	89237.0
9	S_4	Crack (Filling)	A_{41}	276210.0
10	S_4	Patching (Pot hole)	A_{42}	276020.0

The results obtained for resource allocation for case-I B (When 50 % Budget Available) is presented in Table VIII.

TABLE VIII
ANALYSIS AND RESULT FOR RESOURCES ALLOCATION (CASE – I A) CASE-I A = WHEN 50 % BUDGET AVAILABLE

Resources Allocation Based on Proposed Methodology (Priority Index)				
S.NO	**Section**	**Activity**	**Designation**	**Fund Allocated (Rs.)**
1	S_3	Patching (Pothole)	A_{32}	73390.0
2	S_1	Patching (Pothole)	A_{13}	78780.0
3	S_1	Patching (Rutting)	A_{12}	45780.0
4	S_3	Crack (Filling)	A_{31}	340536.0
5	S_2	Patching (Pothole)	A_{32}	373390.0
6	S_4	Patching (Rutting)	A_{42}	276020.0
7	S_1	Crack (Filling)	A_{11}	56520.00
8	S_4	Crack (Filling)	A_{41}	276210.0
9	S_2	Patching (Rutting)	A_{22}	53702.0
10	S_2	Crack (Filling)	A_{21}	55061.0
11	S_4	Patching (Pothole)	A_{43}	43246.0

Resources Allocation Based on Present Practices (Importance of Section)				
S.NO	**Section**	**Activity**	**Designation**	**Fund Allocated (Rs.)**
1	S_1	Crack (Filling)	A_{11}	56520.00
2	S_1	Patching (Pot hole)	A_{12}	45780.0
3	S_1	Patching (Rutting)	A_{13}	78780.0
4	S_3	Crack (Filling)	A_{31}	340536.0
5	S_3	Patching (Pot hole)	A_{32}	373390.0
6	S_2	Crack (Filling)	A_{21}	55061.0
7	S_2	Patching (Pot hole)	A_{22}	53702.0
8	S_2	Patching (Rutting)	A_{23}	89237.0
9	S_4	Crack (Filling)	A_{41}	276210.0
10	S_4	Patching (Pot hole)	A_{42}	276020.0
11	S_4	Crack (Filling)	A_{43}	43246.0

The results obtained for resource allocation for case-IC (When 75 % Budget Available) is presented in Table IX

TABLE IX
ANALYSIS AND RESULT FOR RESOURCES ALLOCATION (CASE – I A) CASE-I A = WHEN 75 % BUDGET AVAILABLE

Resources Allocation Based on Proposed Methodology (Priority Index)				
S.NO.	**Section**	**Activity**	**Designation**	**Fund Allocated (Rs.)**
1	S_3	Patching (Pothole)	A_{33}	3461440.0
2	S_3	Patching (Pothole)	A_{32}	73390.0
3	S_1	Patching (Pothole)	A_{13}	78780.0
4	S_1	Patching (Rutting)	A_{12}	45780.0
5	S_3	Crack (Filling)	A_{31}	340536.0
6	S_2	Patching (Pothole)	A_{32}	373390.0
7	S_4	Patching (Rutting)	A_{42}	276020.0
8	S_1	Crack (Filling)	A_{11}	56520.00
9	S_4	Crack (Filling)	A_{41}	276210.0
10	S_2	Patching (Rutting)	A_{22}	53702.0
11	S_2	Crack (Filling)	A_{21}	55061.0
12	S_4	Patching (Pothole)	A_{43}	43246.0

Resources Allocation Based on Present Practices (Importance of Section)				
S.NO.	**Section**	**Activity**	**Designation**	**Fund Allocated (Rs.)**
1	S_1	Crack (Filling)	A_{11}	56520.00
2	S_1	Patching (Pot hole)	A_{12}	45780.0
3	S_1	Patching (Rutting)	A_{13}	78780.0
4	S_3	Crack (Filling)	A_{31}	340536.0
5	S_3	Patching (Pot hole)	A_{32}	373390.0
6	S_3	Patching (Pot hole)	A_{33}	3461440.0
7	S_2	Crack (Filling)	A_{21}	55061.0
8	S_2	Patching (Pot hole)	A_{22}	53702.0
9	S_2	Patching (Rutting)	A_{23}	89237.0
10	S_4	Crack (Filling)	A_{41}	276210.0
11	S_4	Patching (Pot hole)	A_{42}	276020.0
12	S_4	Crack (Filling)	A_{43}	43246.0

The results obtained using proposed methodology is compared with the practice of resource allocation on ad-hoc basis (i.e. resources are allocated to more important sections first) and results are given From the Table 7 to Table 9. The comparison clearly illustrates that the methodology proposed in this study allocates the limited resources more rationally on the basis of the following facts:

• The proposed methodology allocates resources first to activity A32 i.e maintenance of pot holes on section 3 while based on present practice resources are first allocated to activity A11 i.e maintenance of crack filling on section 1. Further note that overall importance of the section (Ws) of section S1 is 0.87 and for section S3 is 0.86. Section 1 is most important, however the proposed methodology allocates resources to filling of pot holes on section 3 which is nearly equal important to section 1 and also filling of pot holes is more important/urgent as compare to filling of cracks and so on. Hence it may be concluded that proposed methodology allocates resources more rationally considering the following:

- Present distress condition of the section
- Future distress condition of the section
- Importance/urgency of a particular type of distress to be maintained
- Importance of highway class of the section
- Political importance as well as importance to community of the section (i.e importance of the places connected by the section)

IV. CONCLUSIONS

The basic objective of this study was to develop a systematic approach for sustainable maintenance management system for road network in India and a methodology for allocation of limited resources available for maintenance of a road network.

There is an urgent need to develop an appropriate methodology for allocation of limited resources available for maintenance of a road network so that the limited resources available for road maintenance can be utilized rationally and optimally

Methodology is more rational that limited resources needs to be allocated based on the maintenance priority of various activities needs to be carried out on different road / highway sections. Maintenance priority of various activities on identified road network can be determined on the basis of:

Present distress condition of the section
Future distress condition of the section
Importance/urgency of a particular type of distress to be maintained
Importance of road / highway class of the section
Political importance as well as importance to community of the section (i.e. importance of the places connected by the section)

The methodology proposed in this study is illustrated with the help of an example of a small real road network consisting of 4 sections of Vidisha City in the state of Madhya Pradesh. Three different level of funds available i.e. 25 %, 50 % and 75 % is considered and results were compared to assess the suitability of the proposed methodology.

The results obtained using proposed methodology is compared with the practice of resource allocation on ad-hoc basis (i.e. resources are allocated to more important sections first). The comparison clearly illustrates that the methodology proposed in this study allocates the limited resources more rationally.

Methodology allocates resources in the order of their maintenance priority which is determined considering the distress conditions as well as the importance of the section where maintenance activities needs to be carried out. Therefore, the resources are allocated where they are more urgently needed and also considering the importance of the section.

Based on the analysis and result considered in this study, it may be concluded that the methodology presented in this study allocates resources to different maintenance activities considering the condition of distresses, urgency of that distresses to improve that will be maintained by that activity, highway class where that activity to be carried out, political importance as well as importance to community of the section that is to be maintained.

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