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Establishment of Bridge Infrastructure Maintenance Priorities at Network Level for The Case of Extreme User Cost

A case of Morogoro to Dumila segment Tanzania East Africa

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Abstract: The study has developed a strategy for bridge maintenance prioritization based on the maintenance funds limitation. The methodology adopted in this strategy is the simultaneous satisfaction of conflicting objectives in terms of minimization of maintenance cost, maximization of condition rating and the minimization of user cost. The multi-objective index (MOI) is used to give a selection as to which bridge wins the priority and the sequential order of prioritization.

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1. INTRODUCTION

1.1 General Introduction

Bridge is an essential part of our communication system, and therefore it ought to be effective working throughout the whole year. This can be achieved if it maintained regularly, but due to the limitation of fund allocated to the Tanzania road agency, managers should allocate the fund to the mostly severe bridge then followed by other bridge until the next budget is given.

1.2 Problem Statement

It has been observed that some parts of our country are not accessible during the rainy season due to poor bridge conditions. It is very rare for the entire fund requested for maintenance in a specified period to be fully provided by the funding authorities. As such there is always a need to establish priority order of the entire bridge maintenance project in a corridor or an entire region.

1.3 Objectives

To set prioritization criteria of bridge infrastructure maintenance at network level by establish the bridge condition, determine direct maintenance cost of bridges, determine user cost for implementing maintenance of the bridge and Propose strategies toward adoption bridge maintenance prioritization.

1.4 Methodology of the Study

The study has been done through literature review and data collection from Tanzania road agency Morogoro region together with field data. Data analysis was analyzed by excel and the method of mult-objective function that gives which bridge is the first to prioritize then comes to conclusion and recommendation.

2. OVERVIEW ON BRIDGES

A bridge is a structure which is mounted to span physical obstacles such as a body of water, valley or road, for the purpose of providing un-obstructed passage. The need for bridge maintenance is a result of gradual deterioration of the bridge which is subjected to regular traffic flow as well as permanent exposure of the bridge to extreme weather condition.

3. LITERATURE ON BRIDGES

3.1 Bridge Management System

Bridge management system as any or series of engineering and management functions which, when taken together comprises the actions necessary to manage a bridge program. Managing bridge maintenance activities is an important part of any Bridge management systems According to Federal Highway Administration (1995). Maintenance management is a method of controlling resources to accomplish a predetermine level of service through planning, budgeting, scheduling, reporting and evaluating.

3.2 Bridge Inventory

Bridge inventory Data is the identification restrictions, administrative information, geometrical and structural information and all unchanging bridge data. This data is collected by completing field forms called "Bridge Inventory Data Form" see table 3.1.

Table 3.1: Example of the Bridge Inventory Data Form

No	Bridge No	Bridge type	Bridge Name
1	12-0120	Beam bridge	Wami I

3.3 Bridge Inspection

Bridge inspection is another method of bridge management system; the purposes of bridge inspection according to Bridge inspection manual USA (Ralls M.L and Simmons 2002) are

i. To ensure public safety and confidence in bridge structure capacity.
ii. To protect public investment and allow efficient allocation of resources.
iii. To effectively schedule maintenance and rehabilitation operation.
iv. To provide a basis for repair, replacement or other improvement.
v. To ensure that federal funding will remain available for bridge rehabilitation and replacement.

There are five basic types of inspection according to bridge inspection manual USA *(*Ralls M.L and Simmons S.E 2002)

i. Initial inspection - performed on new bridge or when bridge is first recorded
ii. Routine inspection – those regularly scheduled, usually every two years for most normal bridges.
iii. Damage inspections – those performed as a result of collision, fire, flood, loss of support ect. These inspections are also called emergency inspection and are performed on as – needed basis.
iv. In – depth inspections – performed usually as a follow up inspection to better identify deficiencies found in any of the above three types of inspection.
v. Special inspection – performed to monitor a particular deficiency or changing condition. Unusual bridge designs or features such as external, grouted, post tensioned tendons may require a special inspection.

3.4 Bridge Condition

This is one of the main activities of the bridge maintenance management. The condition of a bridge is quantified to be one of five deterioration levels according to the inspection in Bridge life – cycle management systems as follows.

i. Structural coefficient gives an indication of the deficiency of a bridge from the structural point of view.

ii. Functional coefficient quantifies the socioeconomic impact that the closure of a bridge would have on the local community.
iii. Maintenance history coefficient incorporates the maintenance history information of a bridge.
iv. Component deterioration coefficient reflects the damage conditions of the main bridge components.

3.5 Condition Ratings

Condition rating based on the field inspections can be considered as "snapshots in time" and cannot be used to predict future conditions or behavior of the structure. However, the condition Ratings based on the inspections, along with the written comments by the field inspector, acts as the major source of information on the status of the bridge.

The condition Ratings also helps in planning for any necessary repairs or modifications. In addition, the condition Ratings are used as flags when performing overweight permit evaluations.
Condition Ratings are one – digit numbers given by the field inspector to the various components of a bridge as table 3.2 shown.

Table 3.2: Description of Condition Rating

Rating	Description
9	New condition
8	Good condition – no repair needed
7	General good condition – potential exist for minor maintenance
6	Fair condition - potential exist for major maintenance
5	General fair condition – potential exist for minor rehabilitation
4	Marginal condition – potential exist for major maintenance
3	Poor condition – repair or rehabilitation required immediately
2	Critical condition – the need for repair or rehabilitation is urgent
1	Critical condition – study should determine the feasibility of repair
0	Critical condition – condition is beyond repair

Due to the bridge condition element deteriorate with time as Figure 3.1 explained, also when action taken to improve the condition rating the service life is increased as evident in Figure 3.2.

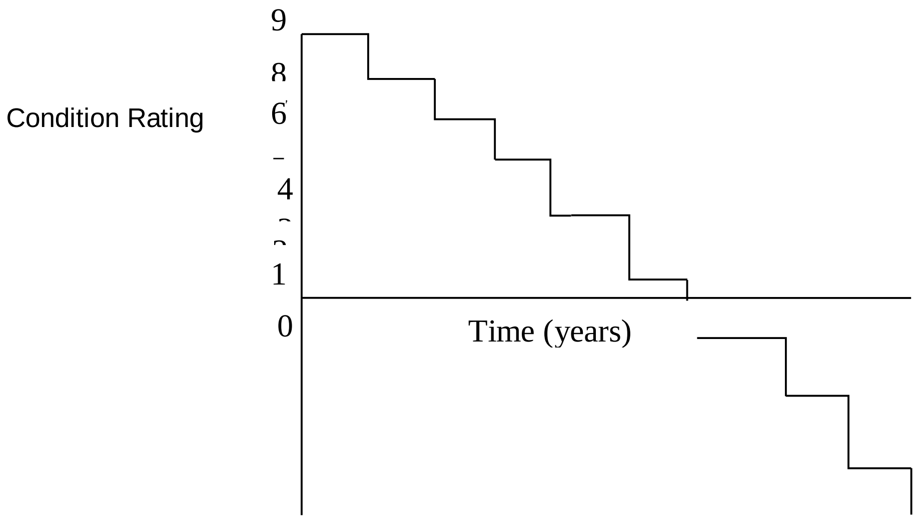

Figure 3.1: Element Deterioration with Time

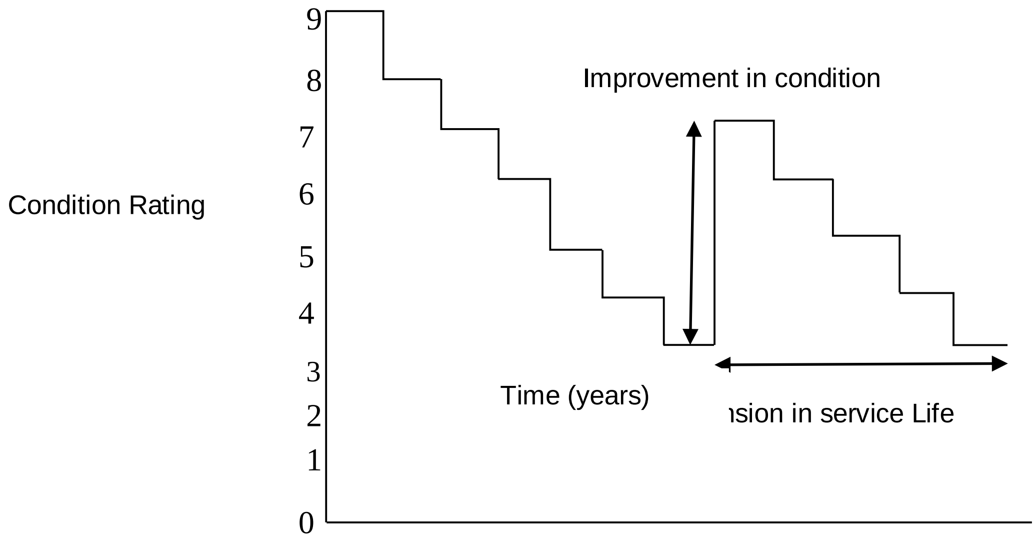

Figure 3.2: Extension in Service Life Due to the Improvement in Condition

3.6 Bridge Cost

Cost is a measure of resources used in planning, design, construction, operations, maintenance, and other activities that provide a bridge and its services to a highway network; such as direct cost, indirect cost, agency cost, user cost, vulnerability cost. Regardless of who pays, costs fall conceptually into two categories of "routine" or "extraordinary."

Routine costs are those which spring from normal development and use of a bridge. Most people will understand that normal costs include at least some periodic spending for maintenance and repair, even if that spending is deferred because of tight budgets. Periodic cleaning of drains, inspections of structural condition, and the value of time lost to congestion when these cleanings and inspections block traffic are similarly included among routine costs.

Extraordinary costs are incurred when unusual events happen. A severe flood, an earthquake, a chemical transport vehicle colliding with the structure, and the like can cause substantial bridge damage and high recovery costs.

3.7 User Cost

User costs typically must be inferred, e.g., from observations of increased fuel consumption and time lost due to increased congestion and assumed values of that time. Some of these costs may be incurred as monetary expenses, e.g., increased vehicle fuel consumption, but most are not.

3.8 Multi-Objective Optimization Problem

The concept of maintenance optimization problem is for the bridge owner or bridge manager seeking to satisfy simultaneously several objectives, such as improvement of bridge safety, minimization of maintenance costs, and minimization of user costs.

The solution of this maintenance management problem can be obtained using the techniques of multi-criteria or multi-objective optimization. However, the notion of optimality is not obvious because of the presence of multiple, incommensurable, and conflicting objectives, so that there is no single optimal solution that yields simultaneously the desired minimum (or maximum) for all objective functions.

3.9 Decision-Making under Multiple Conflicting Objectives

Because of the complexity involved in getting the true optima, compromise solution has been suggested in the literature using a “satisfying” solution that achieves the best compromise between all competing objectives.

A multi-objective index (MOI) has been proposed. The MOI is defined in eq. (1) as the value of the weighted and normalized deviation from the ideal solution f * measured by the family of L_p metrics:

$$MOI_p\ (x) = \left[\sum_{j=1}^{m} w_j^{p} \left(\left| \frac{fj\ (x) - \min fj(x)}{\max fj\ (x) - \min fj\ (x)} \right| \right)^{p} \right]^{1/p} \qquad (1)$$

Where w values depend on the risk tolerance of the decision maker in dealing with the objective. The choice of P indicates the importance given to different deviations from the ideal solution.

4. FINDINGS AND DISCUSSION

SKETCH OF THE CORRIDOR FROM MOROGORO TO DUMILA SEGMENT

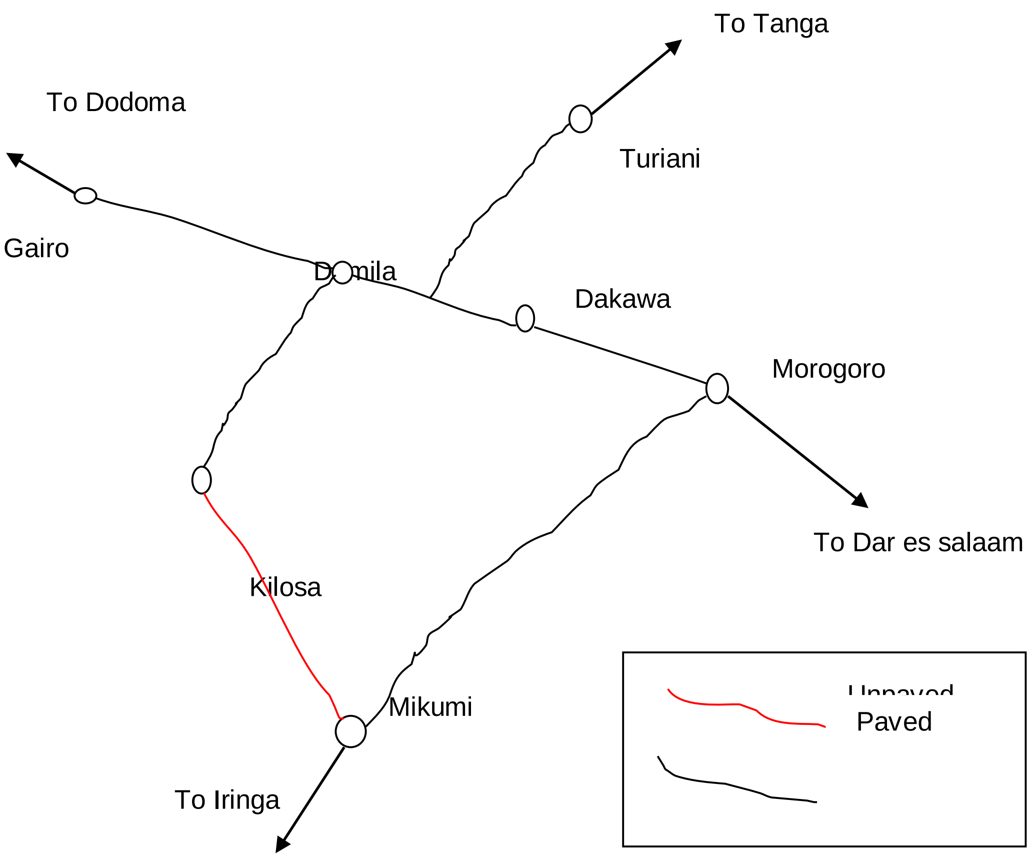

Figure 4.1: Sketch of the Corridor

4.1 Bridge Inventory

This data was collected by completing field form called bridge inventory data form as shown in table 4.1.

Table 4.1: Bridge Inventory form Morogoro to Dumila Segment

No	Bridge No	Bridge type	Bridge Name
1	12-0089	Beam Bridge	Ngerengere
2	12-0120	Beam bridge	Wami I
3	12-0131	Concrete bridge	Magole VII (Mkundi)

4.2 Bridge Inspection

4.2.1 Bridge Inspections for Ngerengere Bridge

According to Tanroads there are three types of inspection informal inspection, General inspection and Major inspection, each one was done due to the request from Tanroad office but Mostly of this research were General inspection. Table 4.2, 4.3, 4.4 and 4.5 shows the inspection report for different bridges and figure 4.2, 4.3, 4.4, 4.5, 4.6 and 4.7 demonstrate the defect noted during inspection.

Table 4.2: Bridge Inspection for Ngerengere Bridge

Element	Type of Damage	Assessment				Remarks	Recommended action
		C	T	M	E		
River course	Vegetation				4	Up stream	Control
Beams	Corrosion			3		all	Treatment
River bank	Erosion			3		1	Replace
Approaches	Missing sign			4		Bridge signs Both	provide

Figure 4.2: Corrosion Defect due to Reinforced Rust within the Concrete

Figure 4.3: Erosion of the Bridge Bank

4.2.2 Bridge Inspections Wami Bridge

Table 4.3: Bridge Inspection for Wami Bridge

Element	Type of Damage	Assessment				Remarks	Recommended action
		C	T	M	E		
River course	Vegetation			4		Up stream	Control
Parapets	Traffic impact		3			one	provide
Beams	Corrosion			4		1	Treatment
piers	N/A						
Abutments Foundation	No Damage						

Figure 4.4 Corrosion Defect due to Reinforced Rust within the Concrete

Figure 4.5 Traffic Impact within the Parapet

4.2.2 Bridge Inspections MagoleVII Bridge

Table 4.4: Bridge Inspection for Magole VII Bridge

Element	Type of Damage	Assessment				Remarks	Recommended action
		C	T	M	E		
River course	Vegetation			4		Up stream	Control
River bed	Desilt			3		1Nos	Excavator
Deck	Crack	3				1	Treatment
piers	N/A						

Figure 4.6: Slab Crack Defect

Figure 4.7: Magole VII Side view Scour Depth Defect

Table 4.5: Traffic Count for Different Bridges along the Corridor

Vehicle Type	Lane-1	Lane-2	Remarks	Time Taken
Passenger Cars	189	205	Ngerengere bridge	09:30-10:30am
Semi-Truck	15	25		
Truck	28	34		
Min Bases	35	38		
Bases	4	34		
Passenger Cars	41	39	Wami I bridge	09:45-10:45am
Semi-Truck	6	8		
Truck	28	39		
Min Bases	5	2		
Bases	4	34		
Passenger Cars	34	30	Magole VII bridge	12:00-13:00pm
Semi-Truck	1	8		
Truck	28	39		
Min Bases	1	2		
Bases	5	3		

Source: Field data (2015)

4.3 Concept of Bridge Priorities

4.3.1 Maintenance cost

This research is based on user cost that has only waiting time due to the nature of the corridor as figure 4.1 shown above, corridor has two alternative root one is from Dumila to Kilosa and another is from Magole to Tanga therefore is too expensive to use those two alternative roots because of the large distances involved, accordingly this research is based only on user cost that are waiting time. Cost incurred by the user when the traffic flow is put on hold awaiting accomplishment of the maintenance activities. Bridge priorities were reached by determining the maintenance cost evident in Table 4.6, 4.7 and 4.8, not only that but also user cost evident in Table 4.9 and Figure 4.8 and bridge condition, all of these item were normalized by normal distribution evident in Table 4.11.

Table 4.6: Maintenance Cost for Ngerengere Bridge

No	Element	Type of Damage	Cost (USD)
1	River Course	Vegetation	9,600
2	Bearings	Debris[broken rocks]	1,828
3	Drainage system	Blocked	600
4	Parapet	Corrosion	8,571
5	Approaches	Missing Sign	5,714
6	Beam	Corrosion	17,142
	TOTAL		43,455

Source: Field data (2015)

Table 4.7: Maintenance Cost for Wami Bridge

No	Element	Type of Damage	Cost (USD)
1	Drainage system	Blocked	9,600
2	Parapet	Traffic impact	15,328

3	Approaches	Missing Sign	5,714
4	Beam	Corrosion	17,142
	TOTAL		47,784

Source: Field data (2015)

Table 4.8: Maintenance Cost for Magole VII Bridge

No	Element	Type of Damage	Cost (USD)
1	Drainage system	Blocked	9,600
2	Parapet	Traffic impact	15,328
3	Approaches	Missing Sign	5,714
4	Beam	Corrosion	17,142
5	River bed	Desilt river course	46,517
6	Deck	Slab crack	8,571
	TOTAL		102,872

Source: Field data (2015)

4.3.2 User Cost for the Road Section Morogoro to Dumila Segment

Table 4.9: Competing Objective Values for the Road Section Morogoro to Dumila Segment

Project	BCI	Duration of maintenance(hrs)	Maintenance cost ($)	Stranded vehicles (cars/heavy vehicles)	User cost ($)
BR-1	6	13	44,000	467/140	196,000
BR-2	4	8	48,000	87/119	87,000
BR-3	7	24	103,000	67/84	161,000
	TOTAL		196,000		444,000

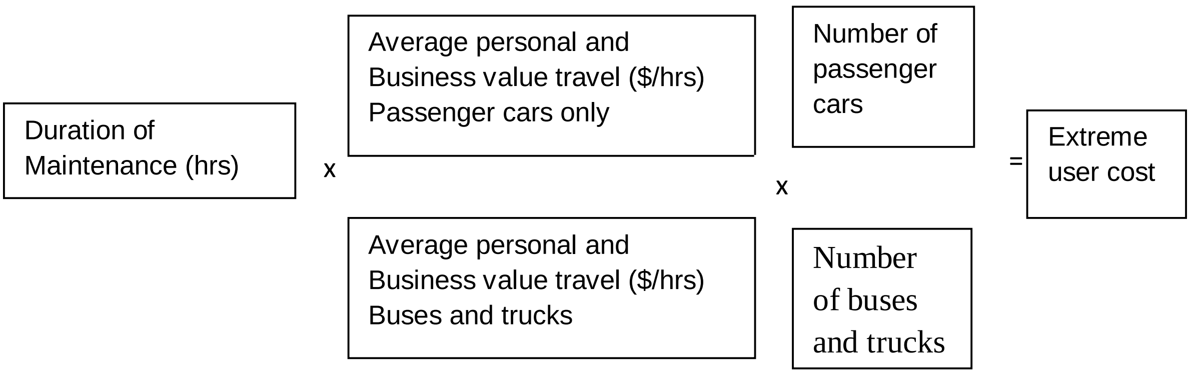

Figure 4.8: Computation of extreme user cost

4.3.3 Normalization of Data and Output of the Data

Bridge condition, maintenance cost and user cost were normalized by distribution through the formula known as standard score with the normalized param

$$\text{Normalized data} = \left[\frac{Xi - \mu}{\sigma}\right]$$

Table 4.10: Computation of Normalized Data

	Condition rating (X)	Maintenance cost (Y)	User cost (Z)	$(Xi-\mu)^2$	$(Yi-\mu)^2$	$(Zi-\mu)^2$
BR-1	6	44000	196000	0.11	441000000	2304000000
BR-2	4	48000	87000	16	2304000000	7569000000

BR-3	7	103000	161000	49	10609000000	25921000000
Total	17	195000	444000	65.11	13354000000	35794000000
Mean	5.7	65000	148000			
Variance				32.6	6677000000	17897000000
SD				5.70	81712.91	133779.67

	Normalized (x)	**Normalized (Y)**	**Normalized (Z)**
BR-1	0.053	0.257	0.359
BR-2	0.298	0.208	0.456
BR-3	0.228	0.465	0.097

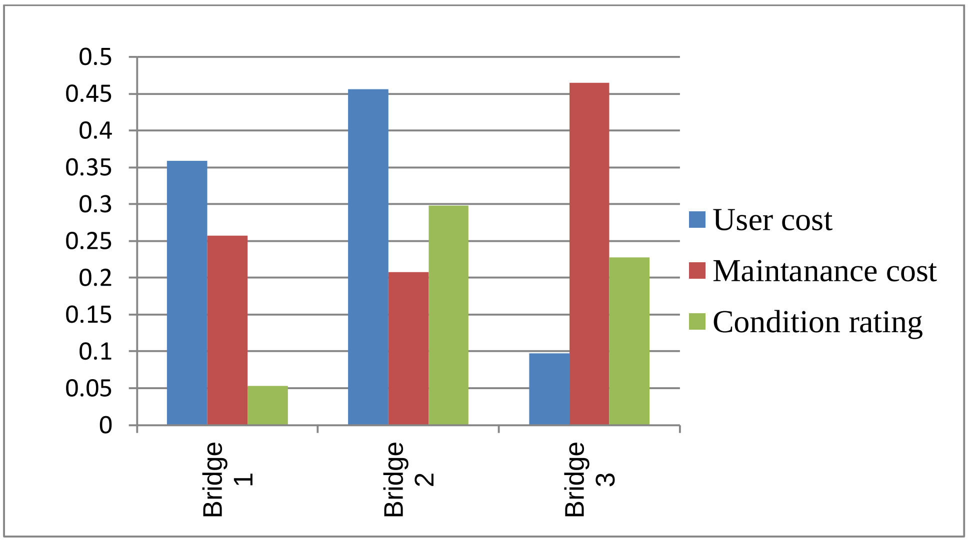

Figure 4.9: Normalized Values of Objective Functions for Bridge Maintenance

Table 4.11: Computation of Multiobjective Based Maintenance Prioritization

	Condition rating (X)	**Maintenance cost (Y)**	**User cost (Z)**	**MOI**
BR-1	6	43455	196001	0.67
BR-2	4	47784	87176	0.38
BR-3	7	102872	160824	0.3

5. SUMMARY CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of the Findings

From findings of the study that was aimed to determine the concepts of establishing the bridge infrastructure maintenance priorities at network level here are the summaries of what was found during research.

i. In consideration of minimum maintenance cost scenario-1 (Figure 4.9) bridge-2 is considered.
ii. But by consideration of excessive user cost scenario-2 (Figure 4.9) bridge-2 is gains the first priority.
iii. However, by consideration of deteriorated condition scenario-1 (Figure 4.9) Bridge-1 is considered to be first priority.

5.2 Conclusions

The initial objectives of this research were to establishing the bridge infrastructure maintenance priorities at network level for the extreme user cost. These general objectives were met through the accomplishments of the research. Due to the conflicting scenarios (Figure 5.1) a solution among the three conflicts is sought through the so-called called Multi-objective based maintenance prioritization showing bridge-1 as the one to be accorded the top priority as reflected in Figure 5.1.

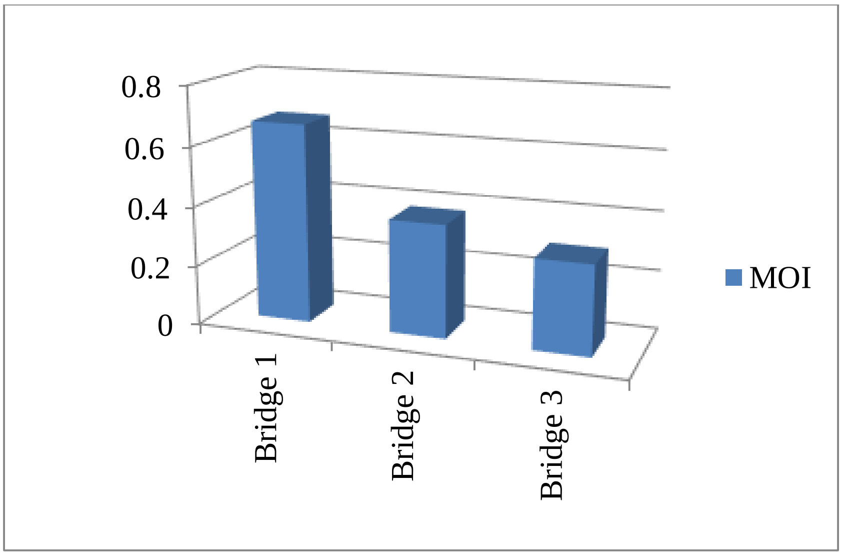

Figure 5.1: Multi-Objective Based Maintenance Prioritization

5.3 Recommendations

5.3.1 General Recommendations

The researcher is recommending to TANROADS the use of bridge prioritization strategy as a key solution of gaining priorities for bridge maintenance by using the multi-objective-based maintenance prioritization due to the limited budgetary allocation from the government authorities.

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