**Proceedings of 14th IOE Graduate Conference**
*Peer Reviewed*
**Year: 2023 Month: December Volume: 14**
**ISSN: 2350-8914 (Online), 2350-8906 (Print)**

# Deterioration Curve to estimate Service Life of Existing Bridge

Shyam Prasad Bhandari [a], Shreedhar Khakurel [b], Samrat Poudel [c], Manoj Sharma Wagle [d]

[a, b, c] *Paschimanchal Campus, IOE, Tribhuvan University, Nepal*
[d] *Pokhara Municipality, Nepal*
bhandarishyam161@gmail.com [a], shreedhar.khakurel@ioepas.edu.np [b], samrat@ioepas.edu.np [c], waglemanoj2017@gmail.com [d]

**Abstract**
A bridge management system (BMS) is the primary tool for the effective management of bridges. Department of Road in Nepal's BMS is based on road classification, traffic volume and detour time for prioritisation of maintenance of bridges at the network level. Maintenance, rehabilitation and replacement strategy based on only condition rating of bridges. A comprehensive BMS based on condition rating, deterioration model, cost model and improvement model is very essential for long-term planning for maintenance, rehabilitation and replacement of bridges. A deterioration model is essential for the bridge management system. In this study, the bridge's deterioration curve is prepared to predict the remaining service life of the bridge. Condition rating of bridges as per DoR report, BMS and as per inspection is used for preparation of curve. Deterministic linear regression and straight-line interpolation methods are implied in this study. The deterioration rate of the Damauli Madi Khola Bridge, Ramadi Kaligandaki Bridge and Baglung Kaligandaki Bridge ares 0.0613, 0.0617 and 0.0628 per year respectively. The effect of maintenance on condition rating and the remaining service life of the bridge is demonstrated by a curve, which shows the importance of timely maintenance of the bridge.

**Keywords**
Bridge Management System, Condition Rating, Deterioration Curve, Service Life

## 1. Introduction

It is known that bridges form an essential part of national infrastructure. They are necessary for connecting various points they are either isolated by artificial or natural obstacles. As per the Department of Road (DoR), the road network in Nepal, totalling approximately 46,000 kilometres, was mainly composed of two main components: the Strategic Road Network (SRN), roughly 14,000 kilometres, and the Local Road Network (LRN), covering nearly 32,000 kilometres. Department of Road (DoR) managed the SRN and SRN bridges, which included national highways, feeder roads, and other nationally significant roads/ bridges. The management of the LRN and LRN bridges, encompassing both rural and urban roads/ bridges, came under the Department of Local Infrastructure (DoLI), province government and local governments. More than 2000 SRN bridge was construction completed by DoR and almost 400 LRN bridge was constructed by DoLI, province government and local government collectively with technical support of the Local Roads Bridge Program (LRBP).

Bridge Management System (BMS) is a systematic and organized approach to managing a network of bridges and aiming to minimize the overall life cycle cost (LCC) of the bridge. [1, 2, 3] BMS includes optimizing the choice of maintenance and improvement actions in order to maximize benefits while minimizing LCC. Bridge management is the means by which a bridge network is cared for from conception to the end of its useful life [4]. Bridge and its components are affected by various factors such as aging, environment, fatigue etc. To maintain the safety and functionality of the bridge timely repair, rehabilitation and replacement action is required. Due to the significant costs and risks involved with structures, bridge maintenance planning is essential [5].

Bridge deterioration is the gradual wearing down of bridge parts over time due to regular use, excluding damage from disasters or accidents. This deterioration happens because of various complicated physical and chemical changes in the bridge parts as they age in different environmental conditions [6]. It is important to develop bridge maintenance strategies based on deterioration models for bridges in order to prioritise and maintain the bridges[7].

Pokhara Muglin highway which is a part of Prithivi highway is upgrading to four lanes from two lanes. As per the DoR database, there are 29 bridges in the Pokhara Muglin section of Prithivi highway (within Gandaki Province), out of which 8 bridges are major bridges. The average age of the bridge along this highway is over 50 years. To cater for the four-lane traffic DoR adopted two options: first is to demolish the existing bridge and construct a full-width four-lane bridge, and second is to use the existing bridge with maintenance and provide a two-lane new bridge. DoR decides the replacement/ maintenance strategy based on the existing condition rating of the bridge only. Out of twenty-nine bridges, fifteen bridges will be replaced by four-lane bridges. Construction of the Siddhartha highway was started in 1964 and completed in 1971, It consists of twenty-five bridges (within the Pokhara Ramadi section). As per DoR, minor to major maintenance of the bridge was recommended as the age of the bridge was almost 50 years. Midhill Highway is under construction but uses the old bridge without replacement. There are twenty-seven bridges along the Midhill highway within Gandaki province, out of which nine are major bridges. The deterioration mechanism of the bridge is to be studied to find the remaining serviceable life of the bridge. Various repair, rehabilitation and replacement strategies for the bridge should be prepared based on the deterioration rate of the bridge. Life cycle costing based on the deterioration model helps planners with long-term economic planning for the maintenance, rehabilitation and replacement of bridges.

The lack of a comprehensive Bridge Management System (BMS) in Nepal, combined with a limited budget with federal, provincial and local government, has led to significant challenges in effectively maintaining bridges and preventing bridge failures. Without a proper BMS, timely maintenance and repairs are not being carried out, resulting in the deterioration of bridge structures. This situation poses a critical problem as the limited financial resources available to the country and agencies are insufficient to address the extensive repair and replacement needs of the bridge network. BMS has been developed to effectively manage a network of bridges while dealing with limited budgets and resources. Numerous BMSs, focus on three key aspects of bridge management: assessing bridge conditions, predicting future deterioration, and making decisions regarding maintenance, repair, or rehabilitation. While a significant amount of literature addresses the first two aspects, there is a lack of studies specifically targeting the optimization of maintenance and repair decisions for bridges [8]. The aim of the research is to develop a bridge deterioration curve for the major bridges along the national highway within Gandaki province using the condition rating to estimate the service life of the bridge.

## 2. Bridge Management System

A bridge management system (BMS) is a logical, methodical approach to planning, designing, building, maintaining, repairing, and replacing bridges, which are essential to the transportation infrastructure. A BMS should help decision-makers forecast future financial requirements and choose the best, most cost-effective options to provide desired levels of service while staying within budget constraints[9]. However, the Bridge Management System adopted by the Department of Roads (DoR) in Nepal is still in its early stages. On February 28, 2013, the Department of Roads under the Ministry of Physical Infrastructure and Transport of Nepal introduced a web-based software for Bridge Management System (BMS). This software was designed to enhance the management of bridge inventory, facilitate organized planning, and establish priorities for investments in the bridge sector. It relies on visual inspections conducted periodically by hired consultants as the primary means of assessment.

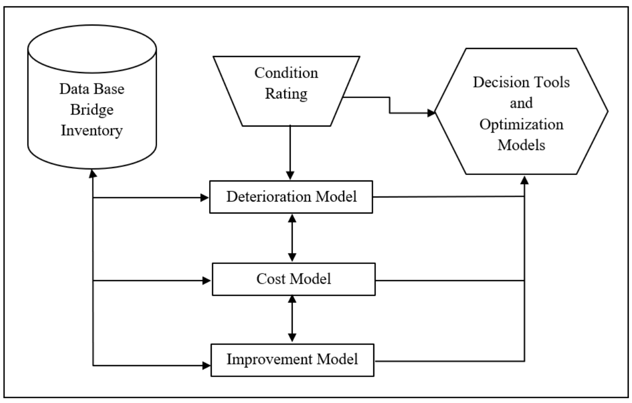


**Figure 1:** Basic Components of BMS (AASTHO, 2001)

A BMS should include the following basic components: condition rating, cost models, deterioration models, and optimization models[3], as shown in Figure 1.

### 2.1 Condition Rating

In order to evaluate the bridge's current state to its condition at the time of construction, condition ratings are used. Typically, an inspection is used to determine the state of the bridge. In order to inform bridge engineers of the degradation of the bridge due to a number of factors, including accidents or damage, fracture, or material breakdown, regular bridge inspection is essential. Bridge engineers can evaluate the need for future maintenance through inspections as well[4]. A condition rating scale of 0-4, based on visual inspection, with 0 being good condition and 4 indicating serious condition, was adopted by DoR at the initial phase of BMS [10]. But the latest version of BMS used a condition rating scale of 0-9[11], 9 being new condition and 0 being critical condition which is shown in Table 1.[11]

**Table 1:** Condition Rating System as per DoR [11]

| Rating | Description |
|---|---|
| N | Not applicable |
| 9 | New condition |
| 8 | Good condition-no repair needed |
| 7 | Generally Good condition -potential exists for minor maintenance |
| 6 | Fair condition- potential exists for minor maintenance |
| 5 | Generally Fair condition- potential exists for minor rehabilitation |
| 4 | Marginal condition-potential exists for major rehabilitation |
| 3 | Poor condition- repair or rehabilitation required immediately |
| 2 | Critical Condition- need for repair or rehabilitation urgent.Facility closed until indicated repair is completed. |
| 1 | Critical Condition-facility is closed |
| 0 | Critical Condition-facility is closed and is beyond repair |

The Bridge Inspection Manual goes into great detail on the methodology and inspection processes. The inspection findings will serve as the foundation for scheduling routine maintenance, setting priorities for extra maintenance, and planning rehabilitation projects. Department of Road listed the category of inspection as tabulated at Table 2.

**Table 2:** Inspection category as per DoR

| Inspection type | Interval | Inspector |
|---|---|---|
| Superficial | Any time | Anyone |
| Routine | 1 years | Divisional staff |
| Principal | 5 years | Consultant/ Bridge unit |
| Special | As required | Various |

### 2.2 Deterioration Model

Bridge deterioration is the process of a bridge's condition deteriorating due to regular operating conditions, excluding damage from quakes, accidents, or fire[12].The degrading process demonstrates the complex combination of physical and chemical alterations occurring within various bridge components. The complex nature of this problem is increased by the different deterioration rates shown by each component[13]. A deterioration model is essential to any bridge management system. Such a model is necessary for BMS decision-making since it increases a bridge's service life by keeping it in better condition while reducing the amount of maintenance needed [14]. The deterioration curve for the bridge is shown in Figure 2[15]. The main types of bridge deterioration models are Mechanistic, deterministic, stochastic and AI models[16]. The mechanistic model deterioration approach relies on a thorough and detailed analysis, focusing on specific bridge elements to predict the micro-response of these components when subjected to applied loads[16]. Deterministic models focus on establishing links between the different elements that contribute to bridge deterioration, including as design, construction, maintenance, environment, and age [17]. Regression analysis of condition data is used in this model, which assumes a distinct trend in the process of bridge deterioration[7]. Straight-line interpolation and regression models are widely used deterministic models. The transport system center developed the linear regression equations and recommended for default deterioration model for bridge[9]. Stochastic models in bridge analysis consider the way a bridge deteriorates as influenced by random factors like time and the condition of its parts. This helps them handle the natural unpredictability and uncertainty of deterioration[9].

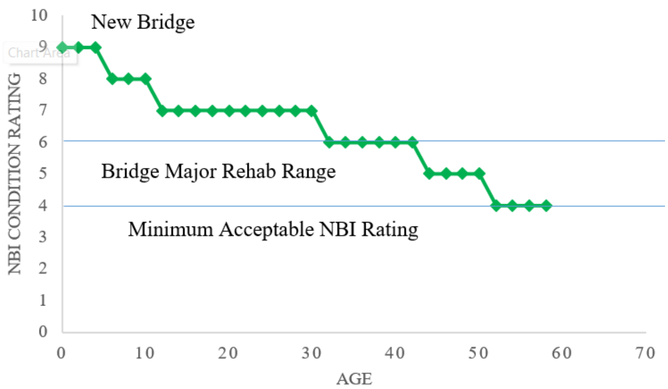


**Figure 2:** Deterioration Curve (Yari, 20180

Life Cycle Cost (LCC) analysis assists in evaluating whether the project's undertaken work justifies its worth from an investor's perspective. This evaluation considers all future costs and uncertainties. LCC analysis ensures the appropriate allocation of funding by establishing a hierarchy of priorities within a design facility. There are limited bridge management systems (BMSs) that incorporate life cycle costing capabilities to assess different design alternatives for bridge repair and maintenance[13]. Life Cycle Cost analysis (LCCA) can assist in making optimal choices and informed decisions for asset management. The importance of using LCCA as a decision-making tool has been recognized by various transportation authorities and decision-makers[18]. Direct costs encompass design costs, construction costs, and maintenance, repair, and rehabilitation costs, while indirect costs or user costs, although not directly visible, are borne by the user[19]. Firstly, in the beginning, a base case is selected for analysis. Then, we identify a problematic functional part that needs attention and create a suitable breakdown of costs. After that, we search for alternatives to address the problematic parts and develop a cost model using calculations. Next, we analyse different scenarios through a sensitivity analysis. Lastly, we thoroughly examine all the costs involved in designing the component that offers the best value for money.

## 3. Methodology

In this study, we focus on three major bridges in Gandaki province. These bridges are important because they connect major highways in the area. The condition rating (CR) of bridges was determined by a superficial inspection using engineering judgements made in accordance with DoR and FHWA guidelines on a scale of 0 to 9. The previous condition rating of the bridge performed by DoR's BMS is used for the preparation of the deterioration curve of the bridge. Due to the limited number of historical data and simplicity, the deterministic linear regression model is used for the preparation of the deterioration curve. The remaining service life of the bridge and its components was determined using a deterioration curve. The overall methodology for the preparation of the deterioration curve is shown in Figure 3.

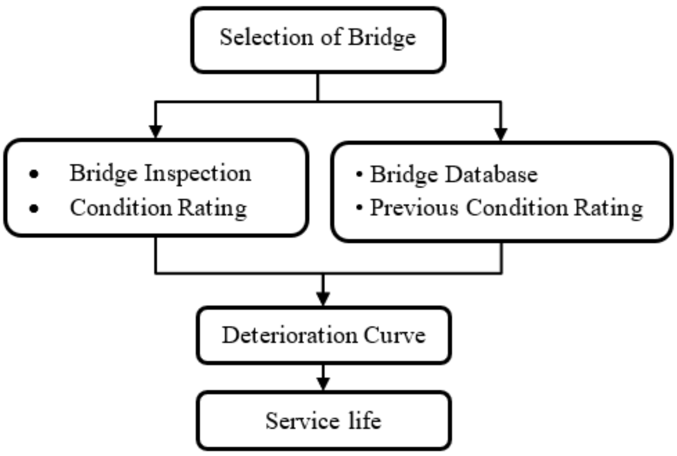


**Figure 3:** Flowchart to prepare deterioration curve of bridge

### 3.1 Selection of Bridge

The study area comprises three major national highways in the Gandaki province: the Prithivi Highway, Siddhartha Highway, and Mid-hill Highway.There are 23 major bridges along the three main national highways in Gandaki province. The detail of type and number is shown in Table 3. Purposive sampling techniques is used for selection of bridge. Among the 23 major bridges, longest bridge from each highway are selected for the case study: Damauli Madi Khola Bridge (DMB), Kaligandaki Bridge, Baglung (KBB) and Kaligandaki Bridge, Ramadi, Syangja (KBR). These bridges represent the deterioration mechanism of the bridge along that highway. Details of the bridge is illustrated in Table 4.

#### 3.1.1 Damauli Madi Khola Bridge (DMB)

The Madi Khola Bridge in Damauli, Tanahun, spans the Madi River and is located along the Prithivi Highway. Construction completed in 2030 BS. It consists of nine spans and measures 370 metres in length overall. The bridge is 7.8 metres wide in total. The bridge's carriageway, which is the component used by cars, is 6 metres wide. This bridge is essential for bridging gaps and facilitating efficient travel along the Prithivi Highway.

**Table 3:** Type of Major Bridge (DoR, 2023)

| Type of Bridge | Number |
|---|---|
| Arch RCC | 6 |
| Steel Plate Girder | 7 |
| Steel Truss | 4 |
| RCC | 5 |
| Balanced Cantilever | 1 |

#### 3.1.2 Baglung Kaligandaki Bridge(BKB)

The Kaligandaki Bridge, Baglung is a bridge that spans across the Kaligandaki River, which connects Baglung and Parbat district. It is situated on the Midhill Highway, making it an important route for transportation. The bridge is 114 meters long and consists of single spans. It has a width of 8 meters. The carriageway is 6 meters wide, ensuring a smooth and safe passage for traffic. The Kaligandaki Bridge plays a significant role in connecting different areas and facilitating convenient travel for people using the Midhill Highway.

#### 3.1.3 Ramdi Kaligandaki Bridge(RKB)

The Kaligandaki Bridge, Ramdi located on the Siddhartha Highway, is a crucial transportation link that stretches over the Kaligandaki River, connecting the Syangja and Palpa districts, Construction was completed on 2029 BS. Spanning 93 meters, this bridge comprises single spans and measures 7.2 meters in width. With a carriageway of 6.7 meters, it ensures a seamless and secure passage for traffic. By connecting various regions, the Kaligandaki Bridge plays a vital role in facilitating convenient travel for individuals utilizing the Siddhartha Highway.

### 3.2 Bridge Database

A comprehensive collection of previous study reports, literature, books, and data related to the study area were gathered from various sources. These documents, reports, data, and information were analyzed thoroughly in the context of the study objectives. The Bridge Management System (BMS) used by the Department of Road (DoR), DoLI's Bridge information management system (BIMS) and their bridge maintenance strategy were reviewed. Then, bridge-related data were collected from various sources, including DOR, DoLI, Infrastructure Development Office (IDO) and other agencies. Secondary data were collected from BMS of DoR, various reports and relevant research articles.

**Table 4:** Detail of Bridge for Study (DoR, 2023)

| SN | Parameters | DMB | BKB | RKB |
|---|---|---|---|---|
| 1 | District | Tanahun | Baglung/ Parbat | Syangja/ Palpa |
| 2 | Bridge type | Steel plate girder | Arch RCC | Steel truss |
| 3 | Total width (m) | 7.8 | 7.2 | 8 |
| 4 | Carriageway width (m) | 6 | 6.7 | 6 |
| 5 | Road name | Prithivi highway | Midhill highway | Siddhartha highway |
| 6 | River stream | Madi river | Kaligandaki river | Kaligandaki river |
| 7 | Length (m) | 370 | 114 | 93 |
| 8 | No. of Span | 9 | 1 | 1 |
| 9 | Age (year) | 50 | 30 | 51 |

Traffic-related data were collected from DoR and the traffic office. Previous condition ratings of bridges at various years were taken from DoR's BMS and reports.

### 3.3 Bridge Inspection

For this study, we conducted a visual superficial inspection, which is a quick assessment of any visible damage. Inspection helps us identify faults and damages that could potentially cause accidents or require expensive maintenance. Inspecting bridges is a critical aspect of the BMS [20]. The main goals of these inspections are to ensure the safety and functionality of existing bridges using various management strategies. It is crucial to conduct inspections on a regular basis, following a thorough, systematic, and consistent approach. Generally, the first step in BMS is visual inspection, where each bridge and its component are visually inspected and given a predefined condition rating, providing a condition evaluation of a bridge. Different countries adopted different condition rating systems and inspection methods [21]. Inspection guidelines of DoR were used in this study. The bridge condition system of DoR (2013) and FHWA as per Table 1 was used for this study. Bridge condition ratings describe how a bridge is deteriorate as compared to when it was new [8].

Normally, the bridge's condition is performed by an inspection. Regular inspections are really important because they help bridge engineers know if the bridge is getting worse for different reasons like accidents, damage, cracks, or the materials breaking down. Inspections also help bridge engineers figure out what maintenance work will be needed in the future. As per DoR, bridges are considered to be functional until a rating of 4 is reached. Bridge Condition Rating (BCR) was calculated using the element condition rating (CR) and their respective weighted (W) [22]. The equation for the calculation of BCR is given in Equation 1 and the respective weighted of various components of the bridge is shown in Table 5.

$$BCR = \frac{\sum CR * W}{\sum W} \tag{1}$$

**Table 5:** Element Weightage in Condition Rating System (Wagle et al. 2022)

| Element | Weightage (%) |
|---|---|
| Approach road | 1 |
| Deck surface | 2 |
| Parapet | 1 |
| Joints | 2 |
| Deck structure | 24 |
| Bearings | 19 |
| Abutments | 14 |
| Piers | 28 |
| Bridge protection | 9 |

### 3.4 Deterioration Curve

Bridge deterioration curves for bridges were prepared based on the existing condition rating of Department of Road (DoR), Bridge management system and condition rating as per site inspection. Historical data of bridge data were collected from Department of Roads and Department of Local Infrastructure, condition rating of bridge as per inspection were analysed. Straight-line interpolation and linear regression deterministic method is used to prepare of curve. Slope of deterioration curve provides the rate of deterioration of bridge [7]. Also, it will be validated with a theoretical bridge deterioration curve as described by Equation 2 [23].

$$Ct = Co - Cf \times (t/T)^{\alpha} \tag{2}$$

Where, $Ct$=condition rating at time $t$, $Co$=initial condition rating, $Cf$= terminal condition rating, $t$ = year of forecast, $T$ = lifespan, and $\alpha$ = shaping factor.

From the deterioration curve, the remaining service life (RSL) of the bridge can be predicted. Equation 3 can be used to find the RSL of the bridge.

$$RSL = \frac{(CR-4)}{S} \tag{3}$$

Where $CR$ is the condition rating of the bridge, $S$ is the slope of the deterioration curve (rate of deterioration).

## 4. Result and Discussion

### 4.1 Condition Rating

The condition rating (CR) of bridges was determined by a superficial inspection using engineering judgements made in accordance with Department of Road (DoR) [11] guidelines on a scale of 0 to 9 as per Table 1. The state of the bridge's components was inspected and evaluated at the MKB, KBR, and KBB. The element condition rating of three bridges is shown in Table 6. Overall Bridge Condition Rating (BCR) is calculated using equation 1 and the weightage of components as per Table 5.

The condition rating of Kaligandaki bridge, Ramadi is 6, as per DoR, the potential exists for major maintenance of the bridge. The deck structure of the bridge was in generally fair condition as its condition rating is 5 and required for rehabilitation. The underside of the concrete deck showed signs of spalling and reinforcement corrosion to large extents. Bridge protection is required to avoid the scouring of abutment. Maintenance of the bridge drainage system and cleaning of drainage spouts are also required.

The condition rating of the approach road and railing is 6, which means major maintenance is required. The wearing of bituminous pavement and the formation of potholes seemed on both sides of the approach road. Resurfacing road pavement, and clearing the road drainage system is necessary. Some part of the railing is broken and corrosion of the steel railing has taken place, which need immediate maintenance action. Some minor deterioration and spalling of pavement surface seemed in the deck surface of the bridge. Pavement near the joints is worn out and accumulation of debris takes place in the gap. Minor scoring of the pier was seen so protection of piers is necessary. Similarly, the Kaligandaki Bridge in Baglung also receives a condition rating of 7 out of 9, indicating the potential for minor maintenance. Bituminous pavement at both sides of the approach road is deteriorating. There is no provision for the drainage system. The bridge deck required maintenance, as some cracks seemed at the bottom surface.

**Table 6:** Condition rating as per inspection

| SN | Bridge element | RKB | DMB | BKB |
|---|---|---|---|---|
| 1 | Approach Road, Embankment and Drainage | 7 | 6 | 6 |
| 2 | Bridge Deck Surface, Drainage and Footpath | 6 | 7 | 7 |
| 3 | Parapet, Railings and Guardrails | 7 | 6 | 7 |
| 4 | Joints | 6 | 7 | 7 |
| 5 | Deck structure | 5 | 8 | 7 |
| 6 | Bearings | 7 | 8 | - |
| 7 | Abutments | 7 | 7 | 8 |
| 8 | Piers | - | 7 | - |
| 9 | Bridge protection | 6 | 7 | 8 |
| | Overall condition rating | 6 | 7 | 7 |
| | Maintenance mitigation | Major | Minor | Minor |

### 4.2 Deterioration Curve

At the time of completion, the bridge's initial condition rating was 9. Condition of bridge and its element deteriorate as a function of time. Previous condition rating of bridge performed by DoR and condition rating as per inspection is used for preparation of deterioration curve of bridge. Due to limited number of historical data and simplicity, deterministic linear regression model is used for preparation of deterioration curve. The actual deterioration curve is discrete rather than continuous since fractional numbers are not considered by the NBI [23] and also by Department of Road rating systems[11]. For the purpose of simplicity, assume that the curve is continuous and linear. Deterioration curve of bridge is prepared based historical data of condition rating of bridge and condition rating as per site inspection. Linear interpolation and regression analysis is used in this study, to prepere the deterioration curve. The slope of deterioration curve provides rate of deterioration of bridge.

### 4.2.1 Kaligandaki Bridge Ramadi

Figure 4 shows the Kaligandaki bridge in Ramadi's bridge deterioration curve. At the time of construction, the bridge had a condition rating of 9. The bridge's most recent condition rating as per DoR, which was revised in 2016, was 6. The rate of degradation, according to the deterioration curve, is 0.0617 per year, which is given by the slope of deterioration curve. According to DoR , bridges are considered as function until such time that they receive a 4 rating. The remaining service life of bridge is determined using Equation 3. Condition rating of bridge as per inspection is 6 at the year of 51 years. According to the deterioration curve and Equation 3, the bridge's remaining service life is approximately 29 years.

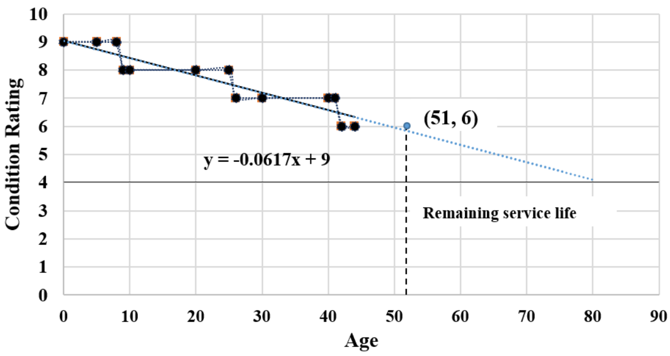


**Figure 4:** Deterioration Curve of Ramdi Kaligandaki Bridge

From the linear regression model, equation for forecasting condition rating of overall bridge is:

$$y = -0.0617x + 9 \tag{4}$$

Where $y$ is condition rating at age of x, x is age of bridge.

Age of the bridge is 51 years, using the equation 4, condition rating at the age of 51 years is 6, which is equal to that as per inspection and rating. Also, the theoretical overall condition rating of bridge according to equation 2 is 6, considering $\alpha$=1.

Remaining service life of bridge is 29.34 years as per equation 3 and taking minimum rating condition from the above three calculations. That means, Kaligandaki bridge, Ramadi can provide service for 29.34 years.After that the bridge is out of service and replacement of bridge is necessary. Also, as per condition rating, rehabilitation of bridge deck is necessary, some minor and major maintenance of other components also required for proper functioning of bridge.

### 4.2.2 Madi Khola Bridge, Damauli

Figure 5 and Figure 6 illustrates the degradation mechanism of the Madi Khola Bridge in Damauli with maintenance and without maintenance respectively. The bridge's initial condition rating upon completion was 9. However, over time, the bridge experiences deterioration. As per Department of Roads the updated overall condition rating of the Madi Khola Bridge in 2019 was 8. Condition rating of bridge was reached 6 at the age of 44 in 2016. According to the Department of Roads (DoR), major maintenance was undertaken on the bridge, resulting in an increase of its rating from 6 to 8. Maintenance of deck, deck surface, railing and river protection work was carried out in 2016-2017. Rate of deterioration of bridge as per deterioration curve is 0.0613 per year. Rate of deterioration is considered same after and before maintenance.

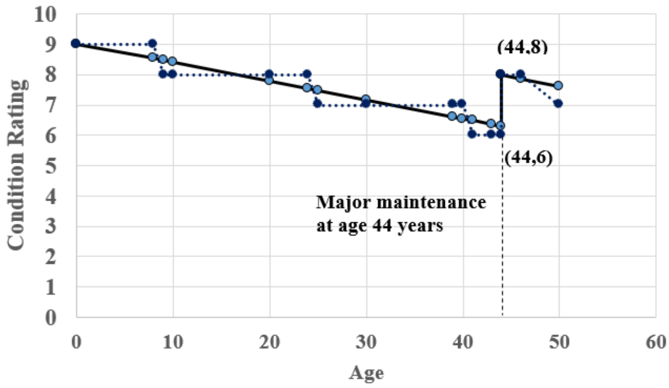


**Figure 5:** Deterioration Curve of Damauli Madi Khola Bridge with maintenance

DoR's Bridge management system (BMS) suggested major maintenance of bridge in 2016 and also take place in FY 2016-17. Deterioration curve of bridge before maintenance is shown in Figure 4, prepared by excluding the condition rating after maintenance.The linear equation for expressing the deterioration mechanism of bridge is given in equation 5. This shows the importance of maintenance of bridge to increase the service life of bridge.

$$y = -0.0613x + 9 \tag{5}$$

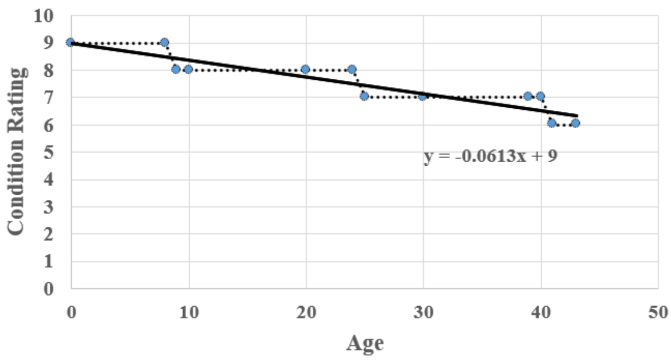


**Figure 6:** Deterioration Curve of Damauli Madi Khola Bridge without maintenance

Using equation 5, condition rating of bridge without maintenance at the age of 50 is 6. But after maintenance of bridge, CR of bridge at age of 44 in 2017 is 8. Now, using the same rate of deterioration, CR at age of 50 is 8. As per inspection, CR of bridge was found 7. There is no significant difference between two CR's. Also using equation 2, theoretical condition rating of bridge is 7. Based on equation 5, the bridge's projected remaining service life is 48 years. Beyond this point, the bridge will no longer be functional, necessitating its replacement. Additionally, in accordance with the condition rating, major maintenance is required for the approach road, drainage system, and railing. Furthermore, minor maintenance of certain other components is also needed to ensure the bridge's proper operation.

### 4.2.3 Kaligandaki Bridge, Baglung

Figure 7 illustrates the degradation mechanism of the Kaligandaki Bridge in Baglung. The bridge's initial condition rating upon completion was 9. However, over time, the bridge experiences deterioration. According to the Department of Roads , the updated overall condition rating of the Madi Khola Bridge in 2016 was 7. The rate of degradation, according to the deterioration curve, is 0.0628 per year. The linear equation for expressing the deterioration mechanism of bridge is given in equation 6. Age of the bridge is 30 years, using the equation 6, condition rating at the age of 30 years is 7, which is equal to that as per inspection and rating. Also using equation 2, theoretical condition rating of bridge is 7. Remaining service life of bridge using equation 2, is 48 years.

Maintenance carried out on the Madi Khola Bridge in Damauli resulted in an extension of its remaining service life. Notably, a major maintenance effort was undertaken on the Madi Bridge during 2016-2017, leading to an increase in its condition rating (CR). In contrast, no maintenance actions were executed on the Kaligandaki Bridge, Baglung and Kaligandaki Bridge, Ramadi. The key point being highlighted is the maintenance effect on the Madi Khola Bridge, where a major maintenance operation was conducted in 2016-2017, resulting in an increased condition rating (CR) and a prolonged remaining service life.

$$y = -0.0628x + 9 \tag{6}$$

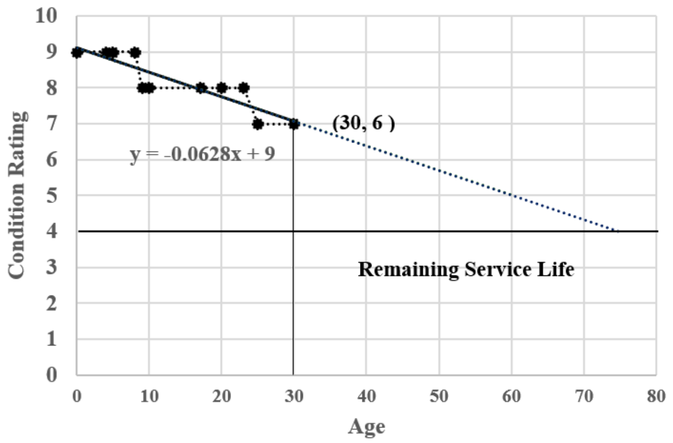


**Figure 7:** Deterioration Curve of Baglung Kaligandaki Bridge

Traffic flow is greater in Madi Khola Bridge, Damauli than in other bridge, but the rate of deterioration rate is small due to the timely maintenance of the bridge.

## 5. Conclusions

A Bridge Management System is a systematic approach to managing bridges that aims to increase their service life economically. In this study, the deterioration behaviour of the three bridge along three highway was studied and the serviceable life of the bridge was estimated using a deteriorate curve. The linear regression method was used for the preparation of the curve. The deterioration rate of Damauli Madi Khola Bridge, Ramadi Kaligandaki Bridge and Baglung Kaligandaki Bridge is 0.0613, 0.0617 and 0.0628 per year respectively. The type of bridge, the volume of traffic, and maintenance methods are some of the factors that affect the rate at which a bridge deteriorates. Three different types of bridges, each with a unique history of maintenance and traffic patterns, were investigated in this study. As a result, these differences cause differences in the rate at which bridges deteriorate. These three bridges were chosen from a variety of highways to serve as exemplary examples of the types of bridges present on their specific routes. Also, the deterioration curve shows the effect of the maintenance of bridges on their serviceable life. The remaining serviceable life of 48 years as major maintenance of the bridge increases the service life of the bridge. The remaining service life can be used for the life cycle costing of the bridge for long-term planning for maintenance, rehabilitation and replacement of bridges. The deterioration mechanism of a bridge is a very important part of a comprehensive Bridge Management System. Stochastic models for the preparation of deterioration curve is recommended for future study.

## References


[1] Jern Lauridsen, John Bjerrum, and Niels Hutzen Andersen. Creating a bridge management system. *Structural Engineering International*, pages 216–220, 1998.

[2] Ronald W. Hudson, R. Frank Carmichael, Stuart W. Hudson, Manuel A. Diaz, and Len O. Moser. Microcomputer bridge management system. *Journal of Transportation Engineering*, 119(1):59–76, 1993.

[3] Mohammed Safi, Håkan Sundquist, Raid Karoumi, and George Racutanu. Integration of life-cycle cost analysis with bridge management systems. *Transportation Research Record: Journal of the Transportation Research Board*, 2292(1):125–133, 2012.

[4] M. J. Ryall. *Bridge management*. Elsevier, 2010.

[5] Gatesi Jean de Dieu, Joao Chingui, and Botir Ergashev. A a review of bridge management system: Deterioration models. *Asian Journal of Engineering and Technology*, 8, 08 2020.

[6] S. Rahman, D J Vanier, Saidur Rahman, and Dana J Vanier. Life cycle cost analysis as a decision support tool for managing municipal infrastructure. *CIB*, pages 1–12, 2004.

[7] Ishwarya Srikanth and Madasamy Arockiasamy. Deterioration models for prediction of remaining useful life of timber and concrete bridges: A review. *Journal of Traffic and Transportation Engineering (English Edition)*, 7:152–173, 4 2020.

[8] Hatem Elbehairy. *Bridge Management System with integrated life cycle cost optimization*. PhD thesis, Library and Archives Canada = Bibliothéque et Archives Canada, 2008.

[9] S. W. Hudson, R. F. Carmichael III, L. 0. Moser, W. R. Hudson, and W. J. Wilkes. Nchrp 300, bridge management system. Technical report, 12 1987.

[10] Department of Road Planning and Design Branch-Bridge Unit. Guideline for inspection and maintenance of bridges 1. Technical report, 2007.

[11] Department of Road Planning and Design Branch-Bridge Unit. Consulting services for updating of bridge management system 1. Technical report, 2017.

[12] J Abed-Al-Rahim and David W Johnston. Bridge element deterioration rates, 1995.

[13] Paul D. Thompson. Bridge life-cycle costing in integrated environment of design, rating. *Bridge life-cycle costing in integrated environment of design, rating.*

[14] AASHTO. Guidelines for bridge management systems, american association of state highway and transportation officials. Technical report, 1993.

[15] Nasser Yari. *New Model for Bridge Management System (BMS): Bridge Repair New Model for Bridge Management System (BMS): Bridge Repair Priority Ranking System (BRPRS), Case Based Reasoning for Priority Ranking System (BRPRS), Case Based Reasoning for Bridge Deterioration, Cost Optimization, and Preservation Strategy Bridge Deterioration, Cost Optimization, and Preservation Strategy.* PhD thesis, 2018.

[16] G. Morcous and Z. Lounis. Probabilistic and mechanistic deterioration models for bridge management. pages 364–373, 2007.

[17] Y I Jiang and Kumares C Sinha. Bridge service life prediction model using the markov chain, 1989.

[18] Hugh Hawk. Nchrp 483, bridge life-cycle cost analysis. Technical report, 2003.

[19] Evaluation of life-cycle cost analysis practices used by the michigan department of transportation. 134(6):236–245, Sep 2008.

[20] Lucy Quirk, Jose Matos, Jimmy Murphy, and Vikram Pakrashi. Visual inspection and bridge management. *Structure and Infrastructure Engineering*, 14:320–332, 2017.

[21] Yaw Adu-Gyamfi, Steven Chase, A. Aktan, and Minaie. Synthesis of national and interna-tional methodologies used for bridge health indices. Technical report, 06 2016.

[22] Manoj Sharma Wagle, Shreedhar Khakurel, and Samrat Poudel. Development of bridge management system for existing bridge in nepal using analytical hierarchy process. *12th IOE Graduate Conference*, pages 1536–1543.

[23] Paul D. Thompson, Kevin M. Ford, Mohammad H. Arman, Samuel Labi, Kumares C. Sinha, and Arun M. Shirole. *Estimating life expectancies of highway assets, volume 1: Guidebook*, 2012.