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Economic Analysis of Under Sleeper Pads (USPs) for Enhanced Railway Infrastructure and Economic Growth in Bangladesh: A Case Study of the Dhaka-Chattogram-Cox's Bazar Corridor

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Abstract
This study examines the economic significance of implementing Under Sleeper Pads (USPs) in Bangladesh's railway infrastructure, focusing on the Dhaka-Chattogram-Cox's Bazar corridor. With increasing demands on rail systems and the need for sustainable, cost-effective infrastructure solutions, USPs present a promising technology. The study assesses the lifecycle benefits of USPs, including cost savings, enhanced track stability, reduced ballast degradation, and their impact on economic growth, particularly in relation to GDP per capita.

Using an Ordinary Least Squares (OLS) linear regression model on 28 years of time-series data from the IMF and project sources, the study explores the relationship between GDP per capita and USP installation. Data includes cost components such as ballast and maintenance expenses, gathered from project records and market sources. Key findings indicate that USP implementation yields significant lifecycle savings, with a Net Present Value (NPV) of USD 18.6 million, an Economic Internal Rate of Return (EIRR) of 18.3%, and a Benefit-Cost Ratio (BCR) of 1.63. The positive correlation with GDP per capita suggests that USPs not only enhance railway efficiency but also support broader economic development. Future recommendations include expanding USP applications across other high-traffic rail corridors and conducting ongoing economic evaluations to maximize cost-effectiveness. Limitations include the model's low explanatory power, indicating potential influences from other factors; further studies could explore external variables impacting railway performance.

Keywords: Under Sleeper Pads (USPs), GDP per Capita, Railway Infrastructure, Economic Impact, Lifecycle Cost Analysis, Track Resilience

Introduction
With rapid advancements in transportation and increasing demand for efficient, sustainable infrastructure, railway systems worldwide are evolving to support economic growth and resilience. In this context, the implementation of Under Sleeper Pads (USPs) represents a significant innovation for railway superstructures, enhancing track stability, reducing ballast degradation, and contributing to lifecycle cost efficiency. This study focuses on the economic impact of USPs in Bangladesh, specifically on the Dhaka-Chattogram-Cox's Bazar corridor, one of the nation's busiest and most strategic railway routes. By evaluating the relationship between USP installation and GDP per capita, this research seeks to demonstrate how this infrastructure technology may influence Bangladesh's economic development.

The primary research questions guiding this study include: How does USP adoption affect track resilience and maintenance costs? And what is the correlation between USP implementation and economic indicators, such as GDP per capita, in Bangladesh? The hypothesis is that USP integration will yield positive economic impacts, as evidenced by a correlation between enhanced railway infrastructure and economic growth metrics. This correlation is anticipated because USP-enhanced rail infrastructure supports high-traffic (both passenger and freight) demands, reduces long-run maintenance costs, and minimizes environmental impacts associated with ballast degradation.

The motivation behind this research stems from Bangladesh's increasing transportation demands and the urgent need to modernize infrastructure to support sustainable economic growth. Inspired by insights gained at the Asian Development Bank (ADB) Railway Innovation Forum in 2019, this study aims to assess the lifecycle benefits and cost-effectiveness of USPs as a transformative solution. Existing literature on USPs in Europe and Asia demonstrates their effectiveness in improving track stability, reducing vibration, and extending ballast life, which collectively lower maintenance costs and increase operational efficiency. Despite these findings, there remains a gap in understanding USP applications within Bangladesh's unique railway landscape, as well as its potential economic benefits at the macro level.

This report addresses these gaps through a systematic review of global USP applications and an empirical analysis specific to Bangladesh's railway system. Using a 28-year time series dataset, an Ordinary Least Squares (OLS) regression model assesses the relationship between USP implementation and GDP per capita, providing insights into the potential economic value of this technology. The findings of this study not only contribute to infrastructure planning in Bangladesh but also offer a model for other developing nations aiming to optimize rail transport systems in support of greater economic objectives.

Objectives

The objectives of this research are to assess the economic impact of implementing Under Sleeper Pads (USPs) in railway infrastructure, specifically on the Dhaka-Chattogram-Cox's Bazar corridor. This includes analyzing USP's effectiveness in reducing track maintenance costs, enhancing track resilience, and extending lifecycle benefits. Additionally, the study aims to explore the correlation between USP adoption and GDP per capita, highlighting its potential contribution to economic development in Bangladesh. The ultimate goal is to provide insights into the cost-effectiveness and sustainability of USP applications in modernizing national railway networks.

Literature Review

Several studies have been conducted on railway USPs, and the following literature review summarizes key findings:

- Harald Loy (2009): Tests in Germany have shown that the use of sleeper pads significantly improves track behaviour and dynamic vibration behaviour compared to traditional ballasted tracks. In Austria, turnouts with USPs were installed in 2002, and measurements showed a reduction in vibrations in the 40 Hz - 50 Hz frequency range [1-3]. USPs are used for noise and vibration protection and to improve track stability, performance, and minimize maintenance costs.
- P. Godart (2015): This study highlights the positive impact of USPs on ground-borne vibration, with a correlation between the USP's dynamic stiffness and vibration levels in the surroundings [4]. USPs reduce pressure between the sleeper and ballast, extending ballast life and distributing the load well over the length of the sleeper.
- Peter Veit (2012): This study found that the benefits of USP use in railway tracks are remarkable, with an Internal Rate of Return (IRR) of up to 20% for high-loaded sections [5]. The study concluded that USPs are most beneficial for tracks carrying a minimum of 13,000 gross tons per day.
- P.J. Grabe et al. (2016): This study found that USPs reduce ballast and sleeper deterioration, lengthening the ballast tamping cycle [6]. The introduction of USPs on heavy-haul lines offers significant advantages in reducing ballast settlement and breakdown, leading to lifecycle cost savings.
- RDSO (2019): Trials in India showed that USP sections experienced 40-50% less track settlement, less pulverization, and considerable savings in maintenance expenditure [7].

The literature review highlights the elasticity, reliability, and economic benefits of USPs, including reduced maintenance costs, extended track life, and improved passenger comfort. The author has examined these benefits in the context of the Dhaka-Chattogram-Cox's Bazar Rail Project Preparatory Facility (DCCRPPF) and explored the economic impact of USPs on Bangladesh's economy.

Methods and Materials

Methodology and Data Collection

Methodology

This study employs a comprehensive methodology to assess the economic impact of implementing Under Sleeper Pads (USPs) in Bangladesh's railway infrastructure, with a specific focus on the Dhaka-Chattogram-Cox's Bazar corridor. The research is based on both secondary data sources and project-specific data, ensuring a robust and reliable analysis. Below is a detailed description of the materials and procedures used for data collection and analysis.

The research utilizes an Ordinary Least Squares (OLS) linear regression model to examine the relationship between the implementation of USPs and GDP per capita, which serves as an indicator of economic growth. The model is applied to a 28-year time-series dataset, allowing for a longitudinal analysis of the economic impacts of USPs. The dependent variable in the model is the impact of USPs on railway infrastructure, while the independent variable is GDP per capita.

To ensure the reliability and robustness of the analysis, the regression model was executed using SPSS (Statistical Package for the Social Sciences), a widely recognized statistical software. The regression output includes key statistical indicators such as R-squared values, significance levels, and correlation coefficients, which help in understanding the sensitivity and strength of the relationship between USP implementation and economic growth. Additionally, descriptive statistical tools, such as scatter plots and correlation analysis, were employed to initially verify the association between the variables, providing a foundation for more precise regression analysis.

Data Sources

The study primarily relies on secondary data sourced from reputable institutions and project records. The key data sources include:

- **GDP per Capita Data:** Sourced from the International Monetary Fund (IMF) for the period under study. This data provides the economic context necessary to analyse the relationship between railway infrastructure improvements and economic growth.
- **Cost-Related Data:** Collected from the Dhaka-Chattogram-Cox's Bazar Rail Project Preparatory Facility (DCCRPPF) under the Ministry of Railways, Bangladesh. This includes detailed cost components such as:
- **Ballast Cost:** The cost of ballast required for the railway tracks, calculated based on market rates and project-specific requirements
- **USP Installation Cost:** The cost of implementing Under Sleeper Pads across the railway corridor
- **Track Maintenance Savings:** Estimated savings from reduced maintenance costs due to the implementation of USPs.
- **Market Price Data:** The cost data for ballast and USPs were derived from recent national and international market rates, as well as from the average unit prices of similar track works completed in other projects. Inflation rates were applied to these unit prices to ensure accuracy.

Economic Evaluation of Under Sleeper Pads (USP)

The economic analysis includes multiple cost components, such as ballast cost, USP installation cost, and track maintenance savings. The analysis was conducted according to the Asian Development Bank (ADB) guidelines (2017), using a discount rate of 9% to calculate Net Present Value (NPV) and Economic Internal Rate of Return (EIRR) [8-10]. Sensitivity analyses were also applied to assess the economic robustness of the USP project under varying cost and benefit scenarios. The economic analysis included the following cost components:

Ballast Cost

- Cost of ballast (at BDT 9619 or USD 91.56 / Cum/m) in million: BDT 11,598 or USD110.4 For track works, unit costs have been based on recent national and international market rates and also by deriving from the average accepted unit prices of recently completed similar track work Projects. Inflation Rates have been applied to the unit prices
- Cost of USP to cover all Components (at BDT 12.9 or USD 0.12 Million/Km): BDT 7,439 Million or USD 70.81
- Saving of (reduced ballast cushion) Ballast at BDT 2.46 or USD 0.023 Million/Km): BDT1,419 Million or USD 13.50 Million
- Capital cost to be invested to implement USP including reduced ballast cushion: BDT17,618.33 Million or USD 167.7 Million
- Additional Capital cost to implement USP: BDT 6,021 Million or USD 57.3 Million

Basis of Costing and Level of Accuracy

The level of accuracy is considered reasonably good, but cost may vary to the extent of further fluctuations in prices of major components and raw materials in global markets.

Total Project Capital Costs

The resulting capital cost estimate for the Project is BDT 757,217.98 million or USD 9,131.91 million, as summarized in Appendix Table.

Standard Factors

The author has used a discount rate of 9% (real, i.e. ignoring inflation) according to an ADB guideline. In keeping with previous rail project analyses, economic costs are computed by multiplying financial costs by the standard conversion factor (SCF) 0.80 and exchange rate in 2022 is BDT 105.1 per USD.

Additional Capital Cost to Implement USP

Economic costs are expressed in monetary values in a fixed year, 2022 for this analysis. Physical contingencies are included but not financial contingencies. Cost inflation and price escalation during construction are not economic costs. Price escalation does not alter the materials used or the end result. Economic costs exclude taxes, which are "transfers" and do not measure resources consumed.

Capital Costs for Under Sleeper Pads

The financial cost has collected from the DCCRPPF project. Excluding taxes, the economic cost of USP is BDT 4.17 billion or USD 0.04 billion, which is 69% of the financial cost of BDT 6.02 billion or USD 0.057 billion. 30 years is adopted as the analysis period, in view of the assets long lives and the greater weight given to later years due to the reduced discount rate (9% instead of 12 %). See Table 1. With USP, the EIRR is 18.3% pa and economic NPV is USD 18.6 million, exceeding the threshold return of 9%.

Year		Costs and Benefits USD Million)					
		Savings in Life Cycle cost					
	Capital cost	**Savings in Recoupment of ballast**	**Saving on Ballast Cleaning after 10th Year**	**Track Maintenance Machine Saving**	**Saving in Leveling-Lining**	**Saving in Ballast cleaning enhanced by 66.7% with Concrete Sleeper with USP**	**NET BENEFIT** (USD Million)
2024							
2025							
2026	**-39.66**						**-39.66**
2027							0.00
2028				**31.62**		**0.87**	**32.49**
2029						1.74	1.74
2030		**2.21**			**10.71**	**1.74**	**14.66**
2031						1.74	1.74
2032						1.74	1.74
2033						1.74	1.74
2034						1.74	1.74
2035						1.74	1.74
2036			**2.52**			**1.74**	**4.26**
2040			2.52			1.74	4.26
2046			**2.52**			**1.74**	**4.26**
2056	**21.95**		**2.52**			**1.74**	**26.21**
NPV	**-29.34**	**1.21**	**8.34**	**20.55**	**5.86**	**11.97**	**18.59**
Source: Author/Economist calculations			**Discount rate @ 9%**	**Economic NPV**	**18.59**	**EIRR**	**18.3%**
						B:C	**1.63**

Table 1: Economic Cost-benefit Analysis of Under Sleeper Pads

Notes:

- Financial costs converted to economic costs using a standard conversion factor of 0.80 and there is no tax or contingency included into economic costs. Residual value 69% after 30 years.
- Saving in Recoupment of ballast after 3 years of initial ballasting due to pulverization at 2.5% of total ballast requirement
- Saving in Ballast due to Ballast Cleaning /Deep Screening of ballast at 3% quantity every year from 10th year of construction to 30th year due to implementation of USP
- Saving on non-Procurement of Track Machine unit due to implementation of USP after 18 months to 30th year (Machines' cost, their Maintenance cost and cost of Engineers/Operators)
- Saving in Levelling-Lining-Tamping at INR 200,000 per Km once in 3 years for 30 years
- Saving in Ballast cleaning at INR 313108/year & Km
- Total savings from the 4th year to 30th year after completion of the construction
- The benefits minus the costs, plus ENPV and EIRR in real terms

Sensitivity Analysis

To ensure the robustness of the economic evaluation, sensitivity analyses were conducted. These analyses examined the impact of variations in investment costs and benefits on the overall economic viability of the USP project. The sensitivity tests included scenarios where the costs of USPs increased or the benefits decreased, allowing for an assessment of the project's resilience to potential changes in economic conditions.

The sensitivity analysis confirmed that the USP project remains economically viable even under scenarios of increased costs or reduced benefits. The Economic Internal Rate of Return (EIRR) of 18.3% and the Benefit-Cost Ratio (BCR) of 1.63 further affirm the economic feasibility of the project.

Sensitivity tests have been carried out and switching values calculated. Table 2 shows the results of the analysis of sensitivity tests and switching values. In this table the blue numbers represent the base case, the black numbers the sensitivity tests, and the red numbers the switching values.

	Economic Net Present Values Discounted at 9%/year									
	USP Costs	**Savings in Recoupment of ballast**	**Saving on Ballast Cleaning after 10th Year**	**Track Maintenance Machine Saving**	**Saving in leveling-Lining**	**Saving in Ballast cleaning enhanced by 66.7% with Concrete Sleeper with USP**	**Net Benefit**	**Real 'Economic IRR(%)**	**Nominal 'Economic IRR(%)**	**Benefit : Cost Ratio***
Additional cost of USP	26.9	1.1	7.7	18.9	5.4	11.0	17.1	18.3	24.60	1.63
Additional cost of USP +20%	32.3	1.1	7.6	18.9	5.4	11.0	11.7			
Additional cost of USP -20%	21.5	1.1	7.6	18.9	5.4	11.0	22.4			
Additional cost of USP +63%	44.0	1.1	7.6	18.9	5.4	11.0	0.0	9.0		1.00
Benefits +20%	26.9	1.3	9.2	22.6	6.5	13.2	25.8			
Benefits -20%	26.9	0.9	6.1	15.1	4.3	8.8	8.3			
Life Cycle benefit -39%	26.9	0.7	4.7	11.5	3.3	6.7	0.0	9.0		1.00
***For ease of reading , only the benefit side of the ratio is shown, i.e. 1.63 is shown rather than 1.63 :1, Note: Author's calculations, Inflation rate(%) 6.30%, Economic data: IMF /2024**										

Table 2: Economic IRR, Sensitivity Tests and Switching Values for USPs

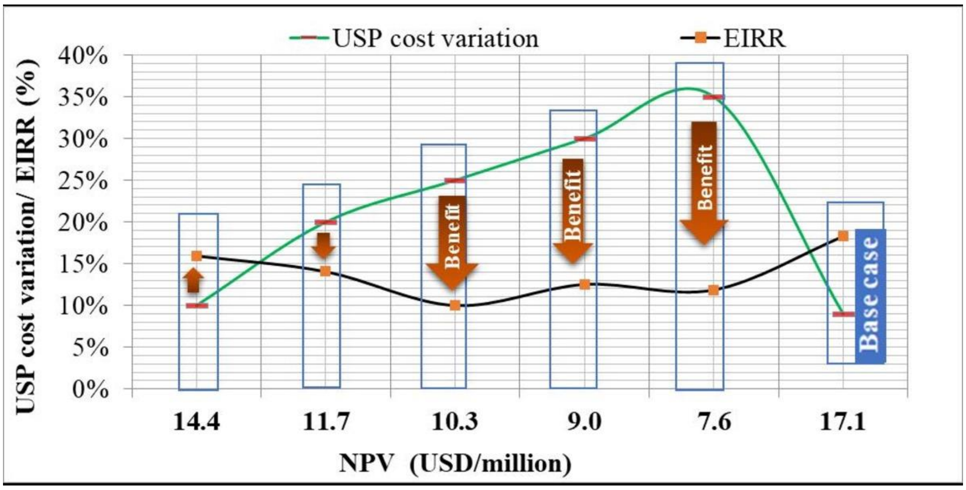

Figure 1: USPs Project Examination by Cost Variation and @ 9% Discount Rate

The EIRR is the discount rate for which the net present value of an investment equals zero (Table 2). Discounting rate of 9% pa is generally in use regarding service lives of 30 and more years. This Project is the feasible from the economic point of view. It has found that under-sleeper pads railway track (USPRT) is a robust project, as sole very substantial cost increases of USPs (63%) or benefit reductions (39%) would affect the overall viability of the project. Table 2 and Figure 2 summarizes the result of sensitivity analysis

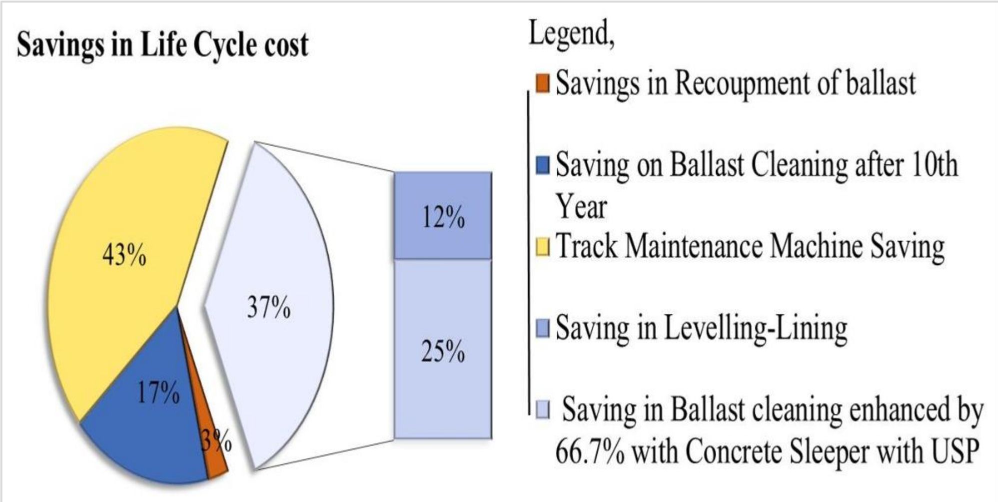

Figure 2: Distribution of Benefits and Saving in LCC

The figure 2-3 shows the net present value (NPV) of the costs and benefits generated by the saving in life cycle cost (LCC). In addition, the distribution of benefits is illustrated graphically. Benefits from track maintenance machine savings represent the majority and correspond to 43% pa whereas benefits from recoupment of ballast Savings 3% pa, Ballast Cleaning (after 10th Year) Savings 17% pa, Levelling-Lining Saving 12.2% pa and Track Machine Operators / Staff savings 25.0% pa. (See, Figure 2).

Descriptive Statistics

Now the author is going to use descriptive statistics first to describe the nature of the variables. The author has used bi-variate models such as scatter plot, correlation coefficient etc. to see if there is association between variables.

So, the author has used the regression model. The author suggested null hypothesis Ho: $\beta = 0$; there is no relation between USPs railway track (USPRT) and GDP per capita. And alternative hypothesis H1: $\beta \neq 0$; there exists relationship between under-sleeper pads (USPRT) and GDP per capita.

The author specifies the following bi-variant regression equation for observing the relationship between two variables. Here α is a constant term and β is the coefficient of X variable that represents GDP. GDP per capita is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. GDPpc data are in current U.S. dollars. And, Under Sleeper Pads (USPs) were first implemented on European railways in the 1980s and are designed to enhance the durability and stability of railway tracks. UPSs improve elasticity, minimize ballast degradation, reduce maintenance needs, and lessen vibrations and noise, creating a more comfortable passenger experience. USPs are adaptable to high-load and high-speed railway lines and are cost-effective, providing extended track life with lower lifecycle costs. The UPSs are particularly valuable for rail networks facing increased demands, as it can reduce environmental impact by limiting the need for additional ballast material.

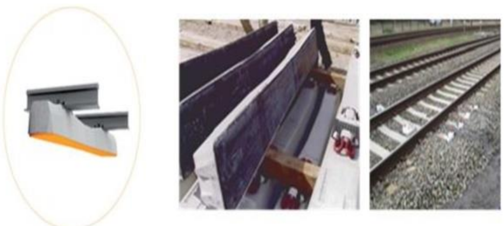

Figure 3: Under Sleeper Pads[6]

Here μ is the error term. It is a variable in a statistical or mathematical model, which is created when the model does not fully represent the actual relationship between the independent variable here GDP per capita (X) and the dependent variable in our case USPs railway track (Y).

Descriptive Findings

Descriptive statistics were used to examine the characteristics of the variables involved, particularly GDP per capita and the impact of USPs on railway infrastructure. Key statistics, including the mean, standard deviation, minimum, maximum values, and variance, were computed for each variable. The data was transformed using a natural logarithm (Ln) to address non-normal distribution, ensuring a more accurate interpretation of the relationship between variables. (Figure 4 and Table 3-6).

Descriptive statistics highlight that the mean GDP per capita over the period studied was approximately USD 1888.345, with substantial variability (standard deviation of USD 1208. 2). For instance, GDP per capita over the period ranged from 491 to 4,640 USD. For USPRT, the average impact level was estimated at 5825737.0 and (standard deviation of USD 6954524.8), with a significant range, indicating variability in the application and economic benefits of USPs over time.

		GDPpc	USP	LnGDPpc	LnUSP
Range	Statistic	4149.000	30756881.000	2.20	2.90
Minimum	Statistic	491.000	1735296.000	6.200	14.400
Maximum	Statistic	4640.000	32492177.000	8.400	17.300
Sum	Statistic	54762.000	168946374.000	212.200	443.300
Mean	Statistic	1888.345	5825737.034	7.317	15.286
	Std. Error	224.352	1291422.838	0.131	0.129
Std. Deviation	Statistic	1208.172	6954524.820	0.705	0.695
Variance	Statistic	1459680.520	48365415471031.500	0.497	0.483
Skewness	Statistic	0.707	3.152	-0.130	1.341
	Std. Error	0.434	0.434	0.434	0.434
Kurtosis	Statistic	-0.402	9.635	-1.288	2.927
	Std. Error	0.845	0.845	0.845	0.845
Valid N		29	29	29	29
Source: calculation by Author/ Transport Economist and SPSS/ 2016software, after Ln used: LnGDPpc and LnUSP					

Table 3: Descriptive Statistics

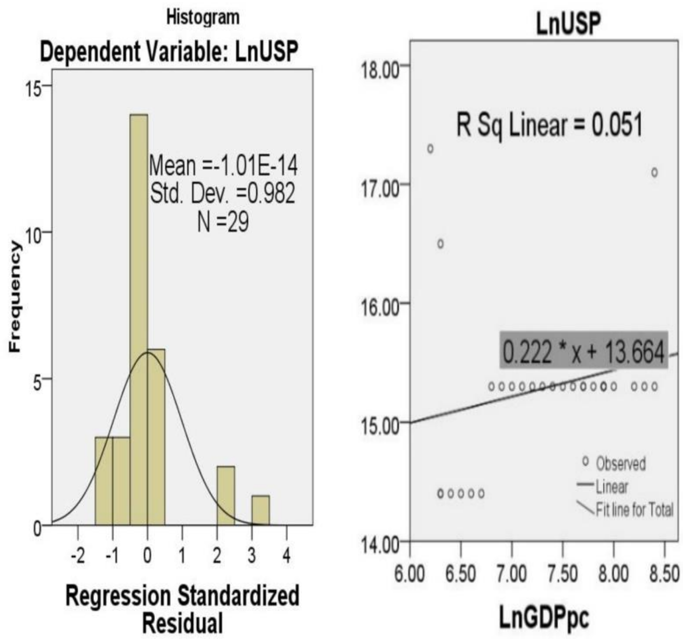

Figure 4: Histogram (Chart -1) and Scatter Plot (Chart -2)

A scatter plot and correlation coefficient analysis demonstrated a likely positive relationship between GDP per capita and the use of USPs, suggesting that as GDP per capita rises, investment in resilient railway infrastructure, such as USPs, becomes more prevalent.

Empirical Results and Discussion

The empirical analysis supports the economic rationale for adopting USPs in Bangladesh's railway system, showing that USPs can enhance the resilience and cost-effectiveness of railway infrastructure. The analysis projects a cumulative increase in GDP growth of approximately 0.0020% over the initial eight years following USP adoption, with incremental increases anticipated over a 30-year project life. This positive correlation, albeit weak, aligns with global findings where infrastructure investments often yield substantial economic returns.

A linear regression model with GDP per capita as the independent variable and USP impact on railway infrastructure as the dependent variable was employed. The analysis yielded the following regression equation:

Coefficients[a]														
Model		Unstandardized Coefficients		Standardized Coefficients	t Stat	P-value	95% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
1	Intercept (Constant)	13.664	1.359		10.054	0.000	10.875	16.452					
	LnGDPpc	0.222	0.185	0.225	1.199	0.241	-0.158	0.601	0.225	0.225	0.225	1.000	1.000
a. Dependent Variable: LnUSP, Source: calculation by Author and Output by SPSS2016													

Table 4: Regression Results

Model Summary[b]										
Model	**R[a]**	**R^2**	**Adjusted R^2**	**Std. Error of the Estimate**	**Change Statistics**					**Durbin-Watson**
					R^2 Change Sig	**F Change**	**df1**	**df2**	**Sig. F Change**	
1	0.225	0.051	0.015	0.690	0.051	1.438	1	27	0.241	1.664
a. Predictors: (Constant), LnGDPpc, Output by SPSS2016 b. Dependent Variable: LnUSP										

Table 5: Model Summary

	df	**SS**	**MS**	**F**	**Significance F**
Regression	1	0.684	0.684	1.438	0.241
Residual	27	12.850	0.476		
Total	**28**	**13.534**			

Source: calculation by Author and Output by SPSS2016, a. Predictors: (Constant), LnGDPpc and b. Dependent Variable: LnUSP, SS=Sum of Squares, MS=Mean Square

Table 6: ANOVA[b]

The findings support the economic rationale for USP adoption, particularly as an infrastructure development that aligns with Bangladesh's broader economic growth. As GDP rises, the increased freight and passenger traffic further justify the use of USPs, which contribute to more resilient and cost-effective railway infrastructure. The positive impact on economic growth is estimated to be gradual, with a cumulative GDP growth increase of 0.0020% in the initial eight years, rising steadily over the 30-year project life.

This research underscores the importance of integrating advanced for Bangladesh railway technologies to support sustainable economic development. Although the model's low explanatory power suggests the presence of other influencing factors, the positive association aligns with global trends where GDP growth often correlates with higher infrastructure investment returns.

Regression Analysis

This study has explored the relationship between Under Sleeper Pads (USPs) usage on railway tracks and economic growth, measured by GDP per capita. A linear regression model with GDP per capita as the independent variable and USP impact on railway infrastructure as the dependent variable was employed. The analysis yielded the following regression equation:

$$Y\ (\text{USPRT}) = \alpha + \beta X_i\ (\text{GDP per capita}) + \mu_i \qquad 0 < \beta < 1 \qquad (1)$$

$$\text{Ln}Y\ (\text{USPRT}) = 13.664 + 0.222 \times \text{Ln}(\text{GDP per capita}) \qquad (2)$$

Where, Yi = USPRT (dependent variable)

X_i = GDP per capita at current market price (independent, or explanatory variable),
α = the intercept 13.664 (positive) this is a constant term, representing the base impact of USPs on railway infrastructure and
β = the slope coefficient (the GDPpc coefficient is 0.222. It is a Ln- linear model), μi= error term

The coefficient (β) of 0.222 suggests that a 1% increase in GDP per capita corresponds to a 0.222% increase in the benefit from USPs on average. This positive association implies that as the economy grows, the advantages of adopting USPs become more substantial.

Statistical Significance and Interpretation

			*. Correlation is significant at the 0.05 level (1-tailed).		*. Correlation is significant at the 0.05 level (2-tailed).	
			LnGDPpc	LnUSP	LnGDPpc	LnUSP
Kendall's tau_b	LnGDPpc	Correlation Coefficient	1	0.334	1	0.334
		Sig. (1-tailed)	.	0.015	.	0.029
		N	29	29	29	29
	LnUSP	Correlation Coefficient	0.33	1	0.33	1
		Sig. (1-tailed)	0.01	.	0.03	.
		N	29.00	29.00	29.00	29.00
Spearman's rho	LnGDPpc	Correlation Coefficient	1	0.37	1	0.37
		Sig. (1-tailed)	.	0.02	.	0.05
		N	29.00	29.00	29.00	29.00
	LnUSP	Correlation Coefficient	0.37	1	0.37	1
		Sig. (1-tailed)	0.02	.	0.05	.
		N	29.00	29.00	29.00	29.00
Source: calculation by Author and Output by SPSS2016						

Table 7: Correlations

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions (Constant)	Variance Proportions LnGDPpc
1	1	1.996	1.00	0.002	0.002
	2	0.004	21.17	0.998	0.998
a. Dependent Variable: LnUSP		Source: calculation by Author and Output by SPSS2016			

Table 8: Collinearity Diagnostics[(a)]

This result suggests that higher GDP per capita correlates with increased usage of USPs, potentially due to a greater ability to fund infrastructure improvements. However, the model's (R2) value of 0.051 indicates (meaning that 5.1% of the variance) that GDP per capita explains only a small portion of the variance in USP adoption, implying that additional factors influence USP investment decisions. The coefficient of correlation (r) = ± 0.225, it can clearly see that there is a positive relationship between GDP per capita and USPRT. However, the positive coefficient indicates a trend where economic growth supports increased adoption of railway advancements such as USPs.

Result: p (T<=t) 0.0000 which is lower than the standard expected P value of 0.05. So, this analysis is statistically significant.

As a consequence, the author can see that findings are matching alternative hypothesis (H1). From these results the author sees that GDP coefficient is positive + 0.222. So, it is implying that for 1 percent increase in the GDPpc, the benefit of under-sleeper pads railway track (USPRT) on the average increases by about 0.222%. Therefore, it can say that there is positive association between GDP per capita and under-sleeper pads railway track (USPRT).

To find out if the parameters are statistically significant, the author has used t-test, z-test, F-Test and p value. Here the calculated t-values for both the variables are much higher that the critical t-values thus, it can say the parameters are statistically significant. P-values are also very low thus the author can say that variables are statistically significant. The values of Standard error are also very low which stats statistically significant variables. Observing the upper and lower values of confidence interval, so it can say zero is not included in this range. Thus, β cannot be zero (β≠0), this supports alternative hypothesis (H1).

Positive Impact on Economic Growth and Life Cycle Benefits

This research shows that the use of USP in railway track will have huge economic benefits which will have a positive impact on the economic growth of the country. Therefore, it has assumed a base case of 7.25 GDP growths; consequently, benefits in the 2028-2036 periods will be 0.0020% within 8 years used of USPs. And GDP will grow by 0.0012%on average from 2036-2046. And GDP will grow by 0.0018% on average from 2046-2056 i.e. GDP would be 7.246% with the project over the 30 years of the project.

From this research, USPs offer various economic benefits, primarily through reduced track maintenance costs, extended track life, and decreased ballast replenishment requirements etc. The economic analysis suggests an Economic Internal Rate of Return (EIRR) of 18.3%, well above the threshold rate of 9%. The Benefit-Cost (B/C) ratio of 1.63 further affirms the economic viability of USP application, particularly for high-traffic railway corridors. The lifecycle savings from reduced ballast maintenance and track upkeep are significant, translating into long-run cost reductions for Bangladesh Railway. Sensitivity analysis confirms that even under scenarios of increased costs or reduced benefits, the project remains economically robust. The most substantial savings arise from decreased track maintenance machinery costs (43% of total savings), followed by ballast cleaning and recoupment.

Findings

The study has carrying out of Under Sleeper Pads (USPs) for railway tracks within the Dhaka-Chattogram-Cox's Bazar Rail Project Preparatory Facility (DCCRPPF) reveals several positive impacts on infrastructure resilience, economic benefits, and operational efficiency.

- **Improved Track Stability and Reduced Maintenance:** USPs significantly enhance the elasticity of the railway track superstructure, reducing ballast wear and tear, vibrations, and ground-borne noise. This improvement minimizes the need for frequent track maintenance and extends the service life of the track components, finally dropping lifecycle maintenance costs
- **Cost-Benefit and Economic Impact:** Economic analysis has done by using a 9% discount rate, shows that incorporating USPs results in a Net Present Value (NPV) of USD 17.05 million and an Economic Internal Rate of Return (EIRR) of 18.3%, well above the threshold rate. The Benefit-Cost (B/C) ratio is calculated at 1.63, indicating that the project yields substantial economic benefits over its cost. These benefits primarily come from reductions in track maintenance costs, machine savings, and ballast cleaning requirements
- **Positive Correlation with GDP:** The study indicates a positive relationship between the implementation of USPs and GDP per capita, as rail infrastructure efficiency directly influences economic activities. Empirical findings suggest that a 1% increase in GDPpc could correlate with a 0.222% enhancement in the economic benefits provided by USPs, underscoring the potential macroeconomic value of modernized rail infrastructure
- **Environmental and Resource Efficiency:** The use of USPs reduces the demand for ballast, which is becoming environmentally and economically costly due to limited natural sources and regulatory constraints. By decreasing ballast requirements, USPs offer an environmentally friendly alternative that also aligns with sustainable resource management goals.

These findings uphold for USPs adoption in Bangladesh's rail infrastructure, emphasizing cost-effectiveness, improved efficiency, and a potential long-term economic contribution, aligning with national goals for sustainable transport development.

Conclusions and Recommendations

The research explored that the economic implications of Under Sleeper Pads (USPs) on Bangladesh's railway infrastructure, focusing on the Dhaka-Chattogram-Cox's Bazar rail corridor. The main objectives were to analyse USPs' cost-efficiency, their impact on track resilience, and their broader economic effects, particularly on GDP. The study applied a 28-year time-series regression model to explore the correlation between USP implementation and GDP per capita. Key findings suggest that incorporating USPs significantly reduces track maintenance costs, extends track life, and requires less ballast, leading to substantial lifecycle cost savings. The economic analysis demonstrated a robust economic internal rate of return (EIRR) of 18.3% and a benefit-cost (B/C) ratio of 1.63, which emphasizing the project's economic viability. Furthermore, USPs appears to align well with national economic growth objectives by supporting increased freight and passenger capacities. The implications of this study highlight the value of investing in advanced rail technologies to enhance Bangladesh's infrastructure resilience, supporting sustainable growth. However, limitations such as the model's low explanatory power suggest further research into other factors influencing economic impacts. Future studies could broaden the scope to assess external variables affecting railway performance, providing a more comprehensive view of USP adoption's economic potential.

There are some recommendations are followings-

- **Implementation of USPs:** Given the cost-effectiveness and lifecycle savings shown in this study, it is recommended to incorporate USPs across other major rail corridors in Bangladesh to optimize maintenance costs and bolster track durability.
- **Regular Economic Evaluation:** Periodic evaluations should be conducted to ensure that economic and operational assumptions are consistent with real-time data, which will help refine investment strategies and maximize long-term benefits.
- **Additional Research:** Further studies should be conducted on the long-term environmental and operational impacts of USPs under different track conditions.
- **Capacity Building:** Railway maintenance teams and engineers should be trained in the installation and maintenance

of USPs to ensure efficient deployment and sustain project outcomes.
- **Partnerships with International Financial Institutions:** Partnerships with institutions such as ADB, WB, IMF, JICA, and EU should be encouraged to secure funding for USP implementation in Bangladesh.

The above measures are expected to maximize the value of investment in USPs, thereby accelerating economic growth and increasing the efficiency, modernization and reliability of Bangladesh's rail infrastructure.

Abbreviations

EIRR or IRR	Economic Internal Rate of Return
BCR	Benefit-C:ost Ratio
USD	The United States dollar
NPV	Net Present Value
DCCRPPF	Dhaka-Chattogram-Cox's Bazar Rail Project Preparatory Facility
BDT	The Bangladeshi taka is the currency of Bangladesh
M	Million
LCC	life cycle cost
USPRT	under-sleeper pads railway track
EU	the European Union
WB	The World Bank
JICA	The Japan International Cooperation Agency

Declarations

The author (Shamema Akter) declares that this manuscript is original, has not been published elsewhere, and is not under consideration by any other publication. The author has confirmed that there is no conflict of interest, financial or otherwise, related to this study. All sources of data and funding have been duly acknowledged, and the work complies with ethical standards in research and publication.

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Appendix

Table A1: Preliminary Capital Cost (All Components)

Description	Route Length (Approx.) (km)	BDT (Million)	USD (Million)	Track cost in BDT (Million)		Track cost in USD (Million)		% pa of USP out of Track cost	% pa of USP out of Project cost
				without USP	with USP	without USP	with USP	with USP	with USP
Component 1	97.01	92,519.81	1,115.77	29340	31329	353.84	377.82	6.78	2.15
Component 2	128.84	128,165.10	1,545.65	42225	44965	509.23	542.27	6.49	2.14
Component 3	11.28	40,368.81	486.84	6109	6327	73.67	76.30	3.56	0.54
Component 4	43.00	77,336.13	932.66	7746	8264	93.42	99.66	6.68	0.67
Component 5A	7.00	17,626.83	212.58	8158	8236	98.38	99.32	0.95	0.44
Component 5B	-	49,232.30	593.73	3153	3153	38.02	38.02	0.00	-
Component 6	27.46	151,250.61	1,824.05	7874	8276	94.96	99.80	5.10	0.27
Component 7	-	74,053.92	893.08	13282	13282	160.18	160.18	0.00	-
Component 8	-	461.47	5.57						
Miscellaneous	-	126,203.00	1,521.98						
Total		**757,217.98**	**9,131.91**	**117,887.0**	**123,830.2**	**1,421.7**	**1,493.4**	**5.04**	**0.78**

(As of 19 May 2019)
Sources: Cost estimate team, DCCRPPF Project, 2019

Table A2: Cost justification for the use of Under Sleeper Pads

Sl. No	Component	Route Km	Track Km		Quantity of Ballast Reqt (CUM)		Cost of Ballast in Million BDT (at BDT 9619/Cum)
			Main line	other than Main line	Main line (at 2.118 Cum/m)	other than Main line (at 1.862 Cum/m)	ballast for Main line
Requirement of Ballast for various Components (with 300 mm for Main line and 250 mm for other than Mainline)							
1	C-1	95.3	190.5	42.3	403,455.7	78,792.4	3,880.8
2	C-2	133.4	262.4	92.2	555,847.9	171,758.3	5,346.7
3	C-3	16.9	20.9	32.3	44,177.2	60,179.8	424.9
4	C-4	43.6	49.6	12.1	105,042.2	22,593.5	1,010.4
5	C-5	7.4	7.4	8.2	15,736.7	15,288.9	151.4
6	C-6	38.5	38.5	30.3	81,458.3	56,483.8	783.5
7	C-7	7.4	7.4	36.3	0.0	13,791.8	0.0
	Subtotal	**342.5**	**576.7**		**1,205,718.1**		**11,597.8**
8	Total quantity of Ballast Required for Main line-				1,205,718.1		

9	Cost of Ballast (at BDT 9619 / Cum) in Million	11,597.8
10	Cost of USP to cover all Components (at BDT 12.9 Million/Km)	7,439.2
11	Saving of (reduced ballast cushion) Ballast at BDT 2.46 Million / Km)	1,418.6
12	Capital cost to be invested to implement USP including reduced ballast cushion	17,618.3
13	**Additional Capital cost to implement USP**	**6,020.5**

Notes:

1. Foreign Exchange Rate is based on 19 December 2022. Exchange Rate (USD 1 = BDT 105.1); Source: Bangladesh Bank
2. Total quantity of Ballast Required for Main line- 1,205,718 Cum/m
3. Cost of Ballast (at BDT 9619 / Cum) in Million 11,598 BDT

Foot Notes:

[1]Data collected from engineering team, DCCRPPF (note, total quantity of ballast required for main line: 1,205,718 main line (at 2.118 cum/m). requirement of ballast for various components (with 300 mm for main line and 250 mm for other than mainline)

[2]Total 576.7 track km for 1-7 components under DCCRPPF project

[3]Guidelines for the Economic Analysis of Projects, ADB 2017

[4]Bangladesh Bank(BB) December 2022

[5]Picture source: from online (https://www.delkorrail.com/track-products/under-sleeper-pads) and experience and types of application using under sleeper pads (USP) and under ballast mats (UBM)/ https://www.oevg.at/fileadmin/user_upload/Editor/Dokumente/Veranstaltungen/2015/Fahrweg/docs/godart.pdf