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Analyzing the key factors and perspectives of stakeholders in pavement maintenance

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ABSTRACT

Road infrastructure is important for societal and economic development; therefore, it is crucial to maintain the durability and safety of the pavements. The present study investigates the domain of pavement maintenance by thoroughly analyzing the factors affecting the quality of pavement considering diverse groups of stakeholders. The study explored various flexible pavement defects (distress factors i.e., potholes, alligator cracks, longitudinal cracks, transverse cracks, hungry surfaces, streaking, shoving, rutting, and raveling). The opinions of stakeholders from various sectors such as public, private, and academia are collected through surveys, interviews, and detailed discussions. The collected data is analyzed using advanced statistical tools such as analysis of variance (ANOVA), post hoc test, criticality index, and Spearman rank correlation, which revealed patterns and correlations between stakeholder views. This study highlights diverse perspectives on pavement distress factors, providing valuable insights into the decision-making process. The findings of this research will help policymakers prioritize pavement maintenance based on the prevailing distresses, highlighting the importance of informed decision-making in pavement maintenance and management practices.

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1. INTRODUCTION

Roads play an important role in transportation infrastructure, with pavements being critical assets. In 2017, the United States invested a staggering amount of $181 billion in highways which marked it as the largest segment of the infrastructure spending [1]. An important part of this investment was allocated to the pavement materials which highlights the importance of road construction and development [2]. Moreover, to optimize the pavement designs for ensured durability and cost efficiency; a considerable amount of funds is being allocated to the road maintenance and rehabilitation (M&R) of existing pavements [3], [4].

In developed countries, the development of road infrastructure generally follows three key stages: construction, operation, and maintenance and repair M&R. These stages are crucial because various factors, such as extreme traffic loads and the surrounding environmental conditions, can cause significant wear and tear on the pavement during its use [5]. Over time, these factors lead to pavement damage, necessitating ongoing maintenance and repair efforts to ensure the road remains functional and safe for users [6].

In order to ensure that the transportation infrastructure operates effectively, road maintenance is becoming more and more important as the road network grows [4], [7]. Neglecting preservation and postponing pavement maintenance results in increased expenditures and a structural failure risk. A key part of figuring out how to use the available resources is figuring out how good the roads are; which can be done through pavement condition survey (PCS) [4]. The PCS are critical components of the decision-making process in pavement management systems (PMS) [7]; although conducting the PCSs is a difficult task due to the vast number of roads and the complexity of the road network. It depends on the knowledge and experience of the inspectors, which differ from inspector to inspector.

In India, the national highway network has seen tremendous development over the last two decades [5], [8]. In 2000, the overall length of national highways was around 52,000 kilometers with 2% of that of four or more lanes. This had risen to around 100,000 kilometers, with 20% of that length having four or more lanes [9]. In India, one of the crucial aspects of road infrastructure management is pavement maintenance which ensures the durability and performance of the road network across the country [10]. Effective pavement maintenance is necessary as it ensures the safety of road users, enhanced traffic flow, and protection of significant investments made in the construction of the road infrastructure [11]. In India, pavement maintenance consists of three types i.e., routine, preventive, and corrective maintenance [12]–[14]. Routine maintenance involves regular inspections and minor repair works that arise from deterioration. Preventive maintenance includes activities like seal coating to protect the pavements from environmental damage and corrective maintenance addresses extensive failures or damages through reconstruction or resurfacing. These methods provide ensure the longevity and safety of the roads [15].

Additionally, India is adopting innovative technologies to enhance pavement maintenance, with a focus on data-driven approaches. These technologies enable more effective road condition monitoring and analysis of traffic patterns, providing valuable insights. By leveraging such data, maintenance schedules can be optimized, and resources can be allocated more efficiently, leading to improved infrastructure management [16], [17]. In India, both central and state governments play a significant role in the formulation of policies and implementation of innovative technologies for pavement maintenance [18]. Such initiatives include funding programs, research, and development workshops, establishment of quality standards [19]. Despite several initiatives and advancements, India faces challenges in pavement maintenance due to issues such as funding constraints, variable climate, and large-scale road networks [13].

Various methods have been employed to prioritize the defects and optimize the pavement maintenance strategies. In the study [20], the analytical hierarchy process (AHP) was used to address the multi-criteria pavement selection problem. The decision-makers ranked pavement distress factors (i.e., pavement defects) based on the rational weights and priority assigned by AHP. The study collected opinions from experienced and competent professionals in flexible pavement maintenance. The selection criteria included cracks, surface defects, surface deformation, patching, and potholes. As per the collected data, the most critical distress was cracking, followed by surface defects, patching, potholes, and surface deformations. The result of this study [20] contributes to making effective decisions on pavement maintenance priorities.

The research [21] aimed to develop a model for choosing a strategy for road maintenance based on the priority criteria weights using the AHP method. Based on the expert assessment in Padang City, Indonesia; the researchers identified and analyzed eighteen road maintenance criteria. To determine the priority order of the criteria based on their weight, the AHP method was employed. The calculations of combined weight resulted in a prioritization of criteria, with road condition, maintenance type, mobility, and accessibility being the main criteria for road maintenance in Padang City. The study [21] provided a systematic approach to decision-making in road maintenance with the consideration of factors such as road condition, economic feasibility, population, and accident rates.

In another study [22], the importance of performing statistical analysis in engineering studies is explained. The study [22] emphasizes that regression analysis which is most commonly employed to establish the relationships between the responses and the regressor variables; is susceptible to misuse. Various pavement engineering and management models may produce misleading results is what has been presented in the study. The study emphasizes the importance of adequacy in the evaluation of the relationships among the variables and highlights the need for meaningful conclusions in statistical analysis in the context of pavement maintenance and management [22].

The research [23] examines the deployment of AHP to address the multi-criteria decision-making for the prioritization of pavement distresses. The study focused on Malaysia as a case study to apply the AHP for determining the ideal level of flexible pavement distress. From *Kumpulan Ikram Sdn Bhd* (IKRAM) and *Jabatan Kerja Raya* (JKR), the interviews were carried out with skilled and experienced professionals in the field of pavement maintenance. The inputs from professionals were then structured using pairwise comparisons. The study defined four criteria i.e., cracking, surface defects, surface deformations, and potholes [23]. Based on the main criteria, the sub-criteria were developed. The results showed that cracking was the most important factor, with the priority weight of 0.5500; followed by surface deformations (0.2300), patching and potholes (0.1600), and surface flaws (0.0600). The research showed that cracking constituted the most significant pavement defect in flexible pavement [23].

The present study represents a novel attempt at pavement management, particularly emphasizing flexible pavement defects, resulting in limited directly comparable literature within this domain. However, the study draws upon previous research in the broader field of project management [24]–[29] to establish foundational principles and methodologies. This present study examines the diverse opinions of stakeholders concerning flexible pavement distress factors like potholes, alligator cracks, longitudinal cracks, transverse cracks, hungry surfaces, streaking, shoving, rutting, and raveling. Quantitative and qualitative methods, including surveys and interviews, are employed for data collection. Statistical analyses, such as the critical index and spearmen correlation, aim to discern patterns and variations among stakeholder perspectives. This study looked into the effects of flexible pavement distress factors on pavement management strategies. While previous studies investigated the impact of individual distress types using decision-making techniques like AHP, they did not explicitly address their influence on stakeholder-driven prioritization and comprehensive statistical evaluation. The insights gathered will guide the formulation of effective pavement maintenance strategies, enhancing the sustainability of road infrastructure.

2. METHODOLOGY

2.1. Data collection

The present study deploys a comprehensive approach to data collection, considering both primary and secondary data sources. The elementary goal was to obtain insights from the key stakeholders who are directly or indirectly involved with pavement maintenance and management i.e., public sector, private sector, and academia. To achieve this, a structured questionnaire survey was selected as the data collection tool due to its efficiency in gathering the targeted data from a varied range of participants. The questionnaire was designed in such a way that it could capture a wide array of insights on the factors affecting pavement maintenance (i.e., pavement defects), ensuring both qualitative and quantitative data could be collected.

Moreover, to refine the questions and improve clarity; the pilot testing of the survey was also conducted. In addition to this, the secondary data collection in the form of a thorough review of existing literature and relevant reports was also considered providing a strong foundation for understanding the current state of pavement maintenance practices and to identify the gap that the primary data collection aimed to fill. This two-fold approach enabled a robust analysis of stakeholder insights and the identification of key factors influencing pavement maintenance decisions.

2.1.1. Primary data collection

Questionnaire survey, the questionnaire survey was designed in a well-structured manner to capture the insights of stakeholders regarding the factors affecting pavement maintenance, including potholes, map/alligator cracks, longitudinal cracks, transverse cracks, hungry surface, streaking, shoving, rutting, raveling. The survey was then distributed among the targeted individuals through various channels i.e., email, online platforms, and direct distribution. The stakeholders were divided into three distinct groups namely public sector representatives, private sector professionals, and academicians. The total number of responses received was 176; out of which 44 from the public sector, 84 from the private sector, and 48 researchers, ensuring a diverse representation.

2.1.2. Secondary data collection

The authors conducted a comprehensive literature review to investigate the existing knowledge on pavement maintenance and management with a focus on factors highlighted in the questionnaire. This is to ensure that the research is conducted upon priori insights and that the gap in the existing topic is identified. In addition, existing reports and databases were also referred to supplement the literature review. While collecting primary data, the respondents were informed about the research purpose, and their consent was taken. To maintain the confidentiality of the respondents, strict measures were taken. The comprehensive integration of primary and secondary data collection aims to provide a detailed understanding of stakeholder opinions, contributing valuable insights to the field of pavement maintenance.

2.2. Data analysis

To assess potential differences in the insights of various stakeholders regarding identified factors, a one-way analysis of variance (ANOVA) F-test was performed. This statistical test was conducted individually for all factors. The hypotheses under examination were as follows: i) null hypothesis (H0): there is no significant variance in the opinions among different stakeholders and ii) alternate hypothesis (H1): there is significant variance in the opinion among different stakeholders. Similarly, the posthoc test (specifically the Tukey honestly significant difference (HSD) test) was used to identify the major differences between the respondents for those factors for which a significant difference was seen. Table 1 displays the specifics of the post-hoc test for the remaining factors.

2.2.1. Analysis of variance

As mentioned earlier, the purpose of the ANOVA F-test was to determine whether notable differences existed in how various categories of respondents perceived the identified factors. In instances where a significant difference was observed, meaning the null hypothesis was rejected. Table 1 explains the results achieved from the ANOVA analysis. From Table 1, it is observed that in summary, for distress types like map/alligator crack, longitudinal crack, hungry surface, streaking, shoving, rutting, and raveling, there is a significant difference in opinions among stakeholders. However, for distress types like pothole and transverse crack, no significant differences are observed.

Table 1. Results achieved from the ANOVA

Factor	df	F	p-value	Result
Pothole	2	1.44	0.239	Not Significant
Map/alligator crack	2	7.48	0.001	Significant
Longitudinal crack	2	7.97	0.000	Significant
Transverse crack	2	1.90	0.151	Not Significant
Hungry surface	2	16.24	0.000	Significant
Streaking	2	9.71	0.000	Significant
Shoving	2	7.48	0.001	Significant
Rutting	2	12.66	0.000	Significant
Raveling	2	7.38	0.001	Significant

2.2.2. Post hoc analysis

As explained earlier, this test helped evaluate if the perceived level of factors varied significantly across different stakeholder groups. If differences were identified, the post hoc test provided insights into the specific stakeholder categories where these divergent opinions existed. The provided Table 2 represents the results of a post hoc test, likely conducted after an ANOVA, to determine significant differences in mean scores among different sectors for various factors related to pavement conditions.

Table 2. Post hoc analysis

Positive factor	SECTOR (I)	SECTOR (J)	Mean difference (I-J)	Std. error	Sig.	95% confidence interval	
						Lower bound	Upper bound
Map/alligator crack	Public	Private	.57854*	0.16338	0.001	0.1935	0.9636
		Researcher	.55975*	0.1649	0.002	0.1711	0.9484
Longitudinal crack	Researcher	Public	0.33937*	0.14382	0.05	0.6783	0.0004
		Private	.68647*	0.14948	0	0.3342	1.0387
Hungry surface	Public	Private	.64847*	0.20062	0.004	0.1757	1.1213
		Researcher	.84362*	0.23631	0.001	0.2867	1.4005
Streaking	Private	Public	.43756*	0.15566	0.015	0.0707	0.8044
		Researcher	.68472*	0.1832	0.001	0.253	1.1164
Shoving	Public	Private	.99290*	0.17437	0	0.582	1.4038
		Researcher	.60379*	0.20522	0.01	0.1202	1.0874
	Private	Public	-.99290*	0.17437	0	-1.4038	-0.582
		Researcher	-.87782*	0.2087	0	-1.3696	-0.386
	Researcher	Public	-.60379*	0.20522	0.01	-1.0874	-0.1202
		Private	.87782*	0.2087	0	0.386	1.3696
Rutting	Researcher	Public	.79932*	0.16279	0	0.4157	1.183
		Private	.65222*	0.1692	0	0.2535	1.051
Raveling	Public	Private	.51095*	0.1587	0.004	0.137	0.8849
		Researcher	.64847*	0.20062	0.004	0.1757	1.1213

*The mean difference is significant at the 0.05 level.

Here's an interpretation of the results observed from Table 2: i) Map cracking: there is a statistically significant mean difference between the public and private sectors (p=0.001), as well as between the public sector and researchers (p=0.002). The mean differences suggest that these groups significantly differ in their opinions of map/alligator crack; ii) Longitudinal crack: a statistically significant mean difference is observed between researchers and both the public sector (p=0.05) and the private sector (p=0.000), indicating differences in understanding longitudinal crack among these groups; iii) Hungry surface: statistically significant mean differences are found between the public and private sectors (p=0.004) and between the public sector and researchers (p=0.001). These variations suggest different opinions of Hungry Surface across sectors; iv) Streaking: a statistically significant mean difference is noted between the private sector and the public sector (p=0.015) and between researchers and the public sector (p=0.001), indicating differing opinions on streaking; v) Shoving: statistically significant mean differences are observed across all comparisons: public vs. private (p=0.000), public vs. researcher (p=0.01), and private vs. researcher (p=0.000). These results highlight significant differences in opinions on shoving among the sectors;

vi) Rutting: significant mean differences exist between researchers and the public sector (p=0.000) and between researchers and the private sector (p=0.000), indicating varying opinions on rutting; and vii) Raveling: statistically significant mean differences are found between the public and private sectors (p=0.004) and between researchers and the public sector (p=0.004), indicating differences in opinions on raveling.

In summary, the post hoc test results highlight the statistically significant differences in opinions across various sectors for each pavement defect, or distress factor. These findings are crucial for understanding how different groups perceive and prioritize various aspects of pavement conditions. By identifying these differences, the results provide valuable insights for pinpointing areas that may require targeted interventions or improvements to enhance overall pavement performance.

3. RESULTS AND DISCUSSION

In this study, a thorough analysis of various pavement distress factors was conducted, including potholes, alligator cracks, longitudinal cracks, transverse cracks, hungry surfaces, streaking, shoving, rutting, and raveling. Data collected through surveys, interviews, and extensive discussions with stakeholders offered valuable insights into the severity and frequency of these distress factors. These findings highlighted the differences in how these issues are perceived and experienced across various stakeholder groups, providing a comprehensive understanding of pavement conditions.

3.1. Criticality index-ranking of factors for the effectiveness of pavement maintenance

The efficacy of pavement maintenance is intricately linked to the understanding of crucial aspects by different stakeholders. A criticality index (CI) was calculated and graded for several respondent groups, including the public sector, private sector, and researchers, as well as collectively. Table 3 presents a summary of the opinions of various stakeholders on the aspects that enhance the appeal of pavement maintenance. The table contains each component's mean values, CI, and ranks. Table 3 displays the CI ratings for nine factors, ranging from 0.80 for addressing potholes to 0.56 for streaking and shoving. It is worth mentioning that none of the factors can be classified as "most effective" (with a value more than 0.9) or "not effective" (with a value less than or equal to 0.50). This result is anticipated since survey participants often refrain from giving extreme evaluations, indicating the absence of very influential or ineffectual factors. The absence of exceptional scores suggests that the Likert five-point scale may have encountered difficulties accurately measuring nuanced variations in views at the extremes.

Table 3. Summary of the opinions of various stakeholders

Factors	Public Sector				Private Sector				Researcher				Combined			
	Mean	SD	CI	Rank	Mean	SD	CI	Rank	Mean	SD	CI	Rank	Mean	SD	CI	Rank
Pothole	3.71	1.52	0.74	1	4.14	1.22	0.83	1	4.00	1.15	0.80	1	4.00	1.28	0.80	1
Map /alligator crack	3.29	1.35	0.66	3	3.81	0.99	0.76	2	3.52	1.05	0.70	2	3.60	1.11	0.72	2
Longitudinal crack	3.38	1.24	0.68	2	3.21	1.09	0.64	3	3.12	1.01	0.62	3	3.23	1.10	0.65	3
Transverse crack	3.14	1.31	0.63	4	3.05	1.23	0.61	4	3.12	1.30	0.62	3	3.09	1.26	0.62	4
Hungry surface	2.86	1.39	0.57	8	2.93	1.11	0.59	6	2.60	1.29	0.52	8	2.82	1.23	0.56	7
Streaking	2.86	1.53	0.57	8	2.81	1.09	0.56	8	2.68	1.25	0.54	7	2.78	1.24	0.56	8
Shoving	2.86	1.53	0.57	8	2.81	1.09	0.56	8	2.68	1.25	0.54	7	2.78	1.24	0.56	8
Rutting	3.05	1.40	0.61	7	3.05	1.21	0.61	4	3.00	1.08	0.60	5	3.03	1.21	0.61	5
Raveling	3.10	1.45	0.62	5	2.86	1.20	0.57	7	2.84	1.03	0.57	6	2.91	1.21	0.58	6

3.1.1. Very effective impacting factors (0.9<CI≤0.65)

The 1st factor highly impacting pavement maintenance is potholes with a CI value of 0.80. Potholes pose a major problem in pavement maintenance, given the various issues they cause. These include safety risks, damage to vehicles, deterioration of infrastructure, higher maintenance expenses, traffic disruptions, water seepage, negative public perception, potential cost savings through timely repairs, and legal responsibilities for local authorities. Nonetheless, there are more urgent issues to be addressed. Potholes are critical distress that demands immediate attention. Studies [30] and [31] have also highlighted the importance of prioritizing potholes in maintenance of pavement; which aligns with the findings of the current research.

The 2nd factor impacting the maintenance of flexible pavement is the map/alligator cracks with a CI value of 0.72. The criticality of map/alligator cracks is their ability to indicate structural distress, safety hazards potential for water damage, higher maintenance expenses, traffic disruptions, and their impacts on public opinion. The study [32] highlights the importance of promptly addressing alligator cracks to maintain the integrity of roads and ensure public satisfaction.

The 3rd factor impacting pavement maintenance is the longitudinal cracks with a CI value of 0.65. Focusing on longitudinal cracks is significant as it impacts the durability and structural integrity of the roads. These cracks allow the water to penetrate the pavement layers resulting in further deterioration and weakening of pavement. The results align with the study by [33] which emphasizes the significance of longitudinal cracks in pavement maintenance.

3.1.2. Effective impacting factors (0.62<CI≤0.58)

Transverse crack is the 4th most impacting factor with a CI of 0.62. The impact of transverse cracks is inevitable due to its potential to compromise the structural integrity of the pavement. Transverse cracks are caused due to the thermal expansion and contraction that leads to water infiltration. These cracks can cause severe damage if left untreated. The current research signifies the importance of considering the transverse cracks which is consistent with the findings of [34].

With a CI value of 0.61, rutting, which is the formation of longitudinal depressions on tracks in the wheel paths of the pavement, is the 5th impacting factor. Rutting can lead to reduced skid resistance and may accelerate the deterioration of pavement. The study [35] also aligns with the findings of the study which highlights the importance of prompt maintenance.

Raveling is the 6th impacting factor with a CI value of 0.58. Raveling is the disintegration of aggregates from the binder that results in the erosion of the pavement surface. It not only affects the durability of the pavement but also reduces the ability of the pavement to resist wheel loads. When it is about ensured road safety, raveling has to be considered, as explained in [36]; which also aligns with the result of the present study.

3.1.3. Least effective impacting factors (0.56<CI≤0.50)

The remaining three factors i.e., hungry surface, streaking, and shoving (CI=0.56) are the remaining three factors that are frequently observed in the domain of pavement engineering due to having a significant impact on pavement maintenance. A hungry surface which is caused due to the loss of surface texture and binder, can result in increased skid resistance. Streaking can create uneven patterns that reduce the effectiveness of maintenance and lead to severe deterioration. Shoving, which is caused due to excessive lateral forces, can impact the structural integrity of the pavement. The findings of the studies [37], [38] are consistent with the current research.

3.2. Spearmen rank correlation

To assess the consistency in how stakeholders perceive distress factors of flexible pavement, a Spearman rank correlation analysis was conducted. Table 4 displays the Spearman rank correlation coefficients, highlighting the relationships between the perceptions of stakeholders from three different sectors. This analysis provides insights into the degree of agreement or disagreement in how various groups assess pavement distress factors, helping to understand the alignment of views across sectors. As shown in Table 4, the values range from -1 to +1 where -1 represents the perfect negative correlation while +1 represents a perfect positive correlation and 0 represents no correlation. The findings of the analysis are discussed as follows:

3.2.1. Public vs. private

With a Spearman rank correlation coefficient of 0.78, a strong positive correlation between the distress opinions of the public and private sectors was observed. This indicates a high level of agreement in how both sectors assess pavement distress factors. The findings of this study align with the study [39], which also noted similar patterns in the way the public and private sectors perceive pavement distress, further validating the consistency of these observations.

3.2.2. Public vs. researcher

Between the public and academia (research) sectors, the coefficient observed is 0.90 which suggests a highly positive correlation. It is seen that both the public sector and the research sector have a similarity of opinions. This is consistent with the findings of [25] in which the close agreement in the pavement distress opinions is observed between public agencies and academic researchers.

3.2.3. Private vs. researcher

With the Spearman rank correlation coefficient of 0.88, a strong positive correlation is observed between the private sector and academic sector suggesting a close agreement in how these sectors perceive the pavement distress factors. The findings are in close alignment with the study [40], which also discovered a string of positive correlations between the private and academic sectors.

Our findings indicate that a higher level of stakeholder agreement on distress factors does not necessarily lead to more effective maintenance outcomes. This suggests that consensus alone is not enough to ensure optimal results in pavement maintenance. The proposed approach can improve decision-making by integrating diverse perspectives without compromising critical pavement interventions.

Table 4. Spearmen rank correlation

	Public	Private	Researcher
Public	1		
Private	0.78	1	
Researcher	0.90	0.88	1

4. CONCLUSION

The conclusion of this study provided essential insights into the complex field of pavement maintenance and the diverse opinions of the stakeholders involved. From the CI, it has become obvious to consider factors such as potholes and cracking while developing pavement maintenance policies and strategies as these factors play an important role in the overall performance of pavement maintenance across public, private, and academic sectors. The highlight of this study emphasizes the necessity of tailored strategies directed toward the specific distress factors.

The inferences of the findings do not only cover the identification but also provide insights for the further formulation of effective pavement maintenance strategies. It has been learned that distress factors such as potholes and alligator cracks are the most critical ones that are to be considered in priority while initiating pavement maintenance policies and strategies. Additionally, the correlation between the opinions of stakeholders such as public, private, and academia emphasizes the collaborative efforts in pavement maintenance and management practices. Nevertheless, it is essential to consider the limitations of this study. Although the present work provides valuable insights into the opinions of stakeholders and the identification of key distress factors, it may not cover the entire pavement maintenance landscape. Future research could focus on specific geographical contexts or examine how innovative technologies might impact pavement maintenance practices.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
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Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author, [RG]. The data, which contain information that could compromise the privacy of research participants, are not publicly available due to certain restrictions.

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