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CYCLING ROUTES TO MITIGATE HEAT STRESS ON CYCLISTS IN TROPICAL URBAN ENVIRONMENTS: AN EXTENDABLE AGENT-BASED MODELING FRAMEWORK FOR STRATEGIC DECISION-MAKING AND BUSINESS APPLICATIONS

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Introduction

Heat stress is a significant concern for cyclists in tropical urban environments, impacting both their well-being and overall thermal comfort. While extensive research has been conducted globally to mitigate heat stress, particularly in cold climate cities where winter heat stress reduces urban thermal comfort, the focus has largely been on pedestrian thermal comfort. Research on addressing heat stress among cyclists, especially in tropical urban settings, remains limited. The optimization of cycling routes to minimize perceived heat stress and improve thermal comfort is an area that has not been extensively explored. This study addresses these research gaps by introducing a novel and effective methodology utilizing an Agent-Based Model to assist urban cyclists in selecting routes that minimize heat stress. By doing so, the study aims to enhance the thermal comfort of cyclists in tropical cities, contributing to a more sustainable and cyclist-friendly urban environment.

Methodology

The research methodology was designed to systematically address the challenge of optimizing cycling routes in tropical urban environments to minimize heat stress. The methodology comprises three stages: survey-based data collection, field measurements, and agent-based simulation analysis. The study began with a survey to identify key factors influencing the route choices of cyclists, followed by the selection of potential routes for detailed analysis. Field data on tree cover and climatic conditions were collected, and Geographic Information System (GIS) tools were used to interpolate and analyze the thermal environment along these routes. To assess the relationship between environmental factors and heat stress, Principal Component Analysis (PCA) was applied. The study then utilized Thom's Discomfort Index to estimate thermal discomfort and employed an Agent-Based Model to determine the most suitable route for minimizing heat stress. This methodology not only provided practical insights for urban cyclists but also laid the groundwork for future research and model development in sustainable urban planning.

The first stage of the study involved conducting a questionnaire survey (Survey 1) to identify the fundamental factors that influence cyclists' route choice preferences. Based on the survey results, multiple potential routes were selected from the origin to the destination. Following this, field data collection was carried out, measuring three parameters and climatic variables, with GIS-based interpolation used to analyze the thermal environment along the chosen routes. Principal Component Analysis (PCA) was then applied to assess correlations between the measured field parameters and roadside thermal characteristics. To estimate thermal discomfort along these routes, Thom's Discomfort Index was utilized. Finally, an Agent-Based Model was employed to determine the most suitable route among the options, with the objective of minimizing heat stress. The results were further validated through subjective feedback. The Makumbura Multimodal Transportation Centre was used as the origin point, and the University of Sri Jayewardenepura in Gangodawila, Nugegoda was chosen as the destination to demonstrate the methodology.

Results and Discussion

The survey results revealed that 63% of respondents preferred an average round-trip distance of 10 km. Additionally, a significant portion of cyclists favored riding in the late afternoon from 3:00 p.m. to 6:00 p.m. Data collection for meteorological analysis was conducted during this timeframe, which is associated with peak urban heat island (UHI) intensity and increased thermal discomfort. Respondents also emphasized the importance of roadside vegetation and trees, noting their value in reducing stress and enhancing physical comfort.

The analysis of heat stress distribution across four alternative cycling routes revealed that Route 2 offered a more thermally comfortable experience compared to Routes 1, 3, and 4. This finding was primarily due to only a smaller proportion of Route 2 being exposed to severe heat stress conditions. A comparative analysis between objective data derived from Thom's Discomfort Index and subjective cyclist responses showed a 66.67% agreement in heat stress estimation, validating Thom's Discomfort Index as a moderately accurate metric for use in the Agent-Based Model. This model was instrumental in optimizing route selection to minimize heat stress for cyclists. Principal

Component Analysis (PCA) further identified temperature and relative humidity as the key factors influencing heat stress levels. In constructing this model several assumptions were taken into consideration. Temperature and relative humidity measurements were considered to be in a random normal distribution, and the speed of the cyclists has been assigned to a random constant value since there is no correlation between the cyclist's speed and the temperature or relative humidity. Accounting for the position of the cycle, the heat stress was calculated from the Discomfort Index equation incorporated in the code which will be represented as a graph.

Figure 1: Interface of NetLogo at Low Temperature and Low Relative Humidity Conditions.

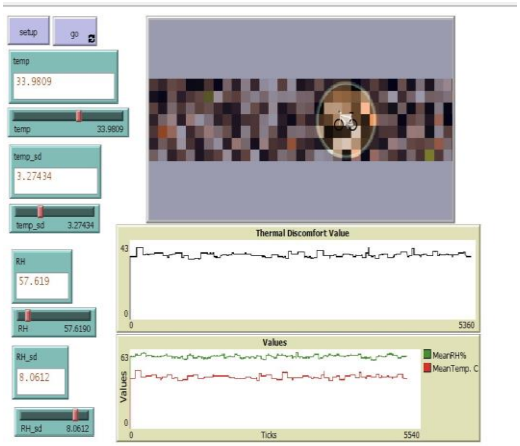

Figure 2: Interface of NetLogo at High Temperature and High Relative Humidity Conditions.

Conclusion

This study contributes to mitigating heat stress among cyclists, supporting sustainable urban development, and enhancing the overall

quality of life in tropical cities. The developed methodology has practical implications, empowering urban cyclists to select routes that reduce heat stress. This study presents a plausible initial framework for developing simulation models that optimize cycling routes by considering the critical factor of heat stress. The current model offers a simple yet effective approach. Future research can build on this foundation to create more sophisticated models and decision-making frameworks for managing perceived heat stress in urban cycling environments.

Keywords: Agent-Based Modeling, Heat Stress, Route Choice Preference, Route Optimization, Urban Cyclists

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