Universal Mobility Equation: Quantifying Mobility

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This paper proposes a **Universal Mobility Equation** aimed at quantitatively modeling mobility beyond conventional transportation-focused perspectives. While mobility is often narrowly associated with vehicles or traffic systems, real-world mobility is fundamentally shaped by a broader set of constraints, including biological capability, technological support, environmental conditions, social authorization, informational capacity, and time availability. Existing mobility studies tend to focus on specific domains—such as social mobility, urban transportation, or individual accessibility—making integrated and cross-domain comparison difficult. To address these limitations, this study introduces a unified quantitative framework applicable to both living organisms and artificial systems.

Inspired by the structural philosophy of the **Drake Equation**, which estimates the existence of extraterrestrial civilizations through a multiplicative combination of necessary conditions, this research models mobility as the product of essential and non-substitutable factors. Mobility is interpreted not merely as movement itself but as **Mobility Power**, defined as the capacity of an entity to move freely, efficiently, and purposefully under given constraints. In this framework, if any enabling factor becomes unavailable, effective mobility collapses, reflecting realistic limitations imposed by physical, social, or regulatory conditions.

The proposed Universal Mobility Equation is formulated as:

$$M = A \cdot f_e \cdot f_b \cdot f_t \cdot f_s \cdot f_p \cdot T$$

where A denotes base propulsion power, f_e environmental allowance, f_b biological or structural mobility capability, f_t technological support and infrastructure access, f_s social authorization or mobility freedom, f_p purposefulness and information-processing capability, and T available movement time. All factors, except propulsion power and time, are normalized between 0 and 1, allowing consistent comparison across diverse entities.

To construct this equation, mobility-related variables were systematically decomposed into seven categories: physical, biological, technological, environmental, social and policy, informational, and temporal factors. Each category integrates contributions from multiple academic domains, including physics, biology, engineering, social sciences, urban planning, computer science, and economics. This interdisciplinary decomposition provides a structured basis for quantifying mobility across heterogeneous systems.

The applicability of the proposed model is demonstrated through comparative case studies involving six entities: a human, a president, a bee, a drone, a tank, and an AI robot. Using standardized scaling values, the mobility index for each entity is calculated and visualized using bar charts and radar charts. The results show that AI robots exhibit high mobility indices primarily due to extended operational time, while the president demonstrates elevated mobility due to strong social authorization, such as prioritized access to infrastructure. Radar chart analysis further clarifies which mobility factors dominate or constrain each entity's movement capability.

Although the current model adopts a strictly multiplicative structure, the study acknowledges potential correlations and dependencies among factors, such as interactions between social status and technological access or between purposefulness and time efficiency. These limitations motivate future research directions, including hybrid or interaction-based formulations, empirical factor estimation using real-world data, and machine learning–based optimization of factor weights. Additionally, the framework may be applied to diverse domains, such as urban mobility inequality analysis, autonomous system evaluation, ecological movement studies, and space exploration planning.

In conclusion, this research advances mobility studies by introducing a **unified, quantitative framework that defines mobility as a form of power rather than mere displacement**. By articulating the structural conditions that enable movement, the Universal Mobility Equation provides a new conceptual paradigm that integrates technological, social, and biological perspectives, serving as a foundation for future interdisciplinary mobility research.