



TOWARDS DYNAMIC ISOCHRONIC MAPPING, TAKING INTO ACCOUNT UNCERTAINTY

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Abstract: *This article explores the theoretical foundations of isochronic mapping, its historical evolution, and its practical applications in modern urban and transportation systems. Beginning with the initial isochrone maps developed by Francis Galton, the study highlights how modern technological advancements have significantly improved the accuracy and usability of such maps. The paper analyzes four main factors influencing accessibility — land use, transport systems, time, and user needs — and their impact on the reliability of isochronic maps. In addition, the work discusses dynamic mapping based on real-time data, its use in emergency services, and approaches to reducing uncertainty.*

Keywords: *Isochrone, isochronic mapping, transport planning, spatial uncertainty, dynamic maps, accessibility components, emergency services, spatial analysis, routing algorithms, time-based visualization.*

Introduction. The term "isochrone" originates from the Greek words "iso" meaning equal and "chronos" meaning time, referring to a line or zone on a map that connects locations accessible within the same time frame. Such maps, particularly in the context of transport and urban planning, visually represent accessibility based on travel time. The concept of isochronic mapping was first introduced in 1881 by Francis Galton, who depicted the number of days it would take to travel from London to various parts of the world [1]. Despite the limited data quality of the time, his approach laid the foundation for modern spatial analysis techniques [2].

Today, the scope of isochronic mapping has expanded dramatically. However, factors such as time variability, road conditions, and traffic load continuously influence the accuracy of these maps. Therefore, it is essential to

develop systems that can identify and measure uncertainty in a way that is understandable to end users [3].

Isochronic Mapping. Following Galton's work, geographers and urban planners began to use isochronic maps as tools for evaluating spatial and temporal accessibility [1], [2]. These maps are especially valuable due to their ability to clearly depict movement opportunities and spatial accessibility. With advances in computational power, GPS technologies, and real-time data-based algorithms, generating isochronic maps has become faster and more accurate [4].

Practical applications of isochronic mapping include:

1. Comparing accessibility across different modes of transportation (e.g., bicycle and public transit) [5].
2. Visualizing access inequality by identifying areas reachable within varying time limits [6].
3. Assisting in urban planning and simulating the impacts of changes in transport infrastructure [7].

Despite these advantages, various sources of uncertainty still hinder the precision of isochronic maps. Ignoring these uncertainties may lead to flawed planning outcomes. Thus, when designing any isochronic map, individual factors, temporal variability, transport mode characteristics, and activity patterns must all be considered [8].

Components of Accessibility and Their Impact. Several critical factors must be taken into account to ensure the accuracy and utility of isochronic maps. Based on the model proposed by Geurs and Van Wee, accessibility is determined by four key components [8]:

1. Land-use component – reflects the quantity, quality, and spatial distribution of opportunities such as employment, services, healthcare facilities, and social infrastructure. It describes the balance between demand and supply within the region.

2. Transport component – describes individual efforts (in terms of time, distance, or cost) required to travel from an origin to a destination using one or more transport modes.

3. Time component – indicates the temporal availability of activities, such as opening hours of facilities, or variability due to factors like traffic congestion or weather.

4. Individual component – represents the capabilities, needs, and resources of individuals, which may vary by age, income, physical ability, or education level.

Each of these components can be a source of uncertainty. Therefore, not only technical, but also social and economic variables must be integrated into the construction of isochronic maps [8].

Dynamic Isochronic Mapping and Uncertainty. To create precise and reliable isochronic accessibility maps, it is essential to consider all four components described by Geurs and Van Wee (2004), ideally in a comprehensive framework. Real-time traffic conditions, environmental factors, and population dynamics must be integrated to reduce uncertainty and enhance decision-making capabilities (see Figure 1)

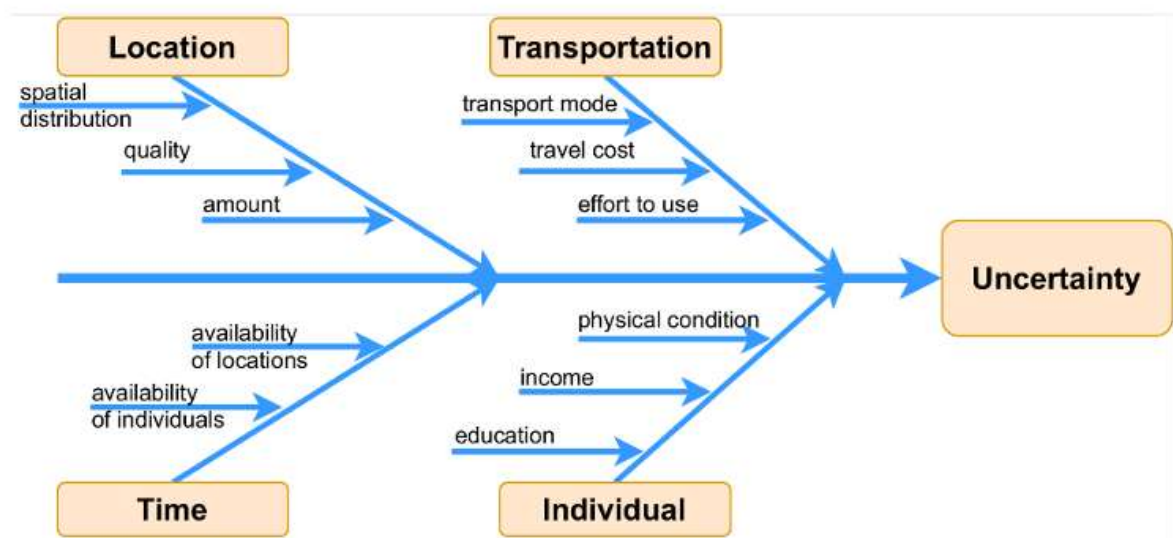


Figure 1. Accessibility components as sources of uncertainty in isochronic mapping.

Dynamic Isochronic Mapping and Uncertainty. In order to enhance the precision and usability of isochronic maps, it is crucial to rely on dynamic datasets. Without integrating real-time variables such as traffic conditions, weather patterns, and demographic fluctuations into planning processes, isochrone maps remain largely theoretical in value [6], [7].

For instance, when planning leisure activities, uncertainty in transport mode selection is generally acceptable, since time constraints are less critical. However, in the case of emergency services—such as ambulances or firefighting units—arrival time is strictly regulated. Any form of uncertainty in such situations may result in severe consequences [3].

Through the use of open-source routing APIs like **Valhalla** or **GraphHopper**, real-time traffic data can be embedded into isochronic mapping models, enabling a more accurate analysis of accessibility under actual conditions [4]. This approach proves particularly relevant in domains such as law enforcement, emergency response coordination, and the efficient functioning of urban infrastructure systems.

Conclusion. Isochronic mapping serves as a valuable tool for visualizing and evaluating accessibility in urban planning and transportation analysis. It provides users with a clear and comprehensible understanding of travel possibilities within a given timeframe and spatial context. However, the effectiveness of these maps is highly dependent on a range of factors, particularly those associated with uncertainty.

To ensure reliable outcomes, any isochrone map must be developed by thoroughly considering transport options, temporal limitations, user-specific needs, and broader socioeconomic conditions [8].

Looking ahead, the integration of isochronic maps with **real-time traffic information, dynamic population data, and behavioral analytics** will significantly increase their practical value. Moreover, this advancement opens new opportunities for deploying isochronic maps in critical domains such as emergency services, public health, environmental monitoring, and beyond.

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