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Fundamentals of Driving Patterns and Driving Cycles

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Preface

The primary objective of this textbook is to present in an organized manner the knowledge accumulated worldwide regarding driving patterns and driving cycles (DCs). These two concepts are fundamental for improving the energy efficiency of vehicles, decarbonizing the transport sector, and promoting smart mobility in urban centers.

Through a systematic review of the literature published in the last 15 years, this document establishes a common language, offers a comprehensive review of the methodologies to construct DCs, identifies research opportunities, and presents recommendations on the best practices in the DC construction process that considers new trends and state of the art in technology.

This textbook results from an initiative of the Latin American Network for Research in Energy and Vehicles (RELIEVE, https://redrelieve.com/). RELIEVE is a non-profit organization that seeks to generate and strengthen capacities in its LATAM nodes, in a way that they could serve as technical support to government entities and private companies in topics related to energy, environment (air), vehicles, transport, and smart mobility. To

achieve this objective, RELIEVE develops joint research projects, disseminates scientific knowledge, and trains human talent through specialized training and academic exchange among its participants.

More than 70 experts from 19 universities and four companies from seven Latin American countries actively participate in RELIEVE. Dr. Huertas from Tecnologico de Monterrey leads this organization.

The following table lists the main contributors to the present book.

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Contents

Introduction

1

Jenny Díaz Ramírez and José I. Huertas

Abstract

A driving cycle is a time series of speeds that represent a driving pattern, which in turn describes the typical driving behavior observed in a specific region. The construction of driving cycles (DCs) has been a significant research focus due to their role in evaluating vehicle energy demands and pollutant emissions, and more recently, in optimizing energy management systems for electric vehicles (EVs). This chapter introduces the essence and purpose of the book 'Fundamentals of Driving Patterns and Driving Cycles' and provides an overview of its content.

1.1 Introduction to Fundamentals on Driving Patterns and Driving Cycles

A driving pattern "describes how people drive in a given region", while a driving cycle (DC) is "a time series of speeds representing that driving pattern" [1–3]. DCs are constructed mainly (i) to evaluate the vehicle's energy consumption and emissions, (ii) as a tool to design vehicle components (e.g., powertrain), and (iii) evaluate energy management and logistics strategies in several applications involving motorized vehicles. The DC construction process has received much attention from the scientific community in the last

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decades, looking for DCs that adequately represent the local driving pattern of the region or activity under study.

Through a systematic review of the literature published over the last fifteen years, combined with the expertise of the authors contributing to each chapter, this document establishes a common language, offers a comprehensive review of the methodologies to construct DCs, identifies research opportunities, and presents recommendations on the best practices in the DC construction process that considers new trends and state of the art in technology.

The development of DCs has been a research topic for the last 30 years. It is crucial for governmental environmental authorities and applied research centers focused on the energy usage and environmental footprint of vehicles [2]. In the contexts of smart cities, climate change, emerging vehicle technologies, and information technology, the interest in DCs worldwide has steadily grown. This interest has been fostered by the need to accurately identify DCs that allow the evaluation of the energy demands and pollutant releases from vehicles, as well as the optimization of energy management systems for electric vehicles (EVs) and powered hybrid EVs.

Despite its relevance, there is no standard method for constructing DCs and evaluating their degree of representativeness. In addition, there is a continuing demand for new DCs that meet specific requirements and for methodologies that easily allow the construction of personalized DCs from low-cost experimental data [4]. Progress in telematics, connected-vehicle systems, and big-data technologies has made it feasible and effortless to obtain data from vehicles to analyze driving characteristics, construct representative DCs, and develop efficient driving techniques and adaptive control strategies for EVs. Thus, a DC construction method with high accuracy and less experimental effort would be highly appreciated when dealing with big-data management [5].

In addition, the existing DCs cannot keep pace with the changing mobility dynamics: road infrastructure improvements, vehicle fleet composition change, the rising number of vehicles on the roads, and the focus on environment and resource protection. As a result, significant research has been conducted to develop new and representative DCs tailored to specific contexts [6, 7].

Although there is a progressive increase in quantity of publications on DC development, as shown later in Fig. 2.2a, there is a lack of an updated study that could offer, in a comprehensive way, a DC construction method. Most studies focus on specific steps of the process ignoring others that we consider fundamental to justifying the representativeness of a DC.

The primary objective of this work is to systematically present the knowledge accumulated in recent years concerning driving patterns and the DCs construction methods. The initial step involves establishing a common language related to driving patterns and DCs. Then, based on a systematic literature review, describe the steps required to construct a representative DC. We will also identify research trends and opportunities and, when appropriate, offer authoritative guidance on the best practices, considering contemporary

technological advancements. Finally, seven practical cases of DC construction in various Latin American regions are presented, demonstrating the application of the construction process developed in this book.

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Systematic Literature Review on Driving Cycles

2

Jenny Díaz Ramírez, Jessica Gissella Maradey Lázaro, and José I. Huertas

Abstract

This chapter outlines the methodology used to conduct a systematic literature review on driving patterns and driving cycles. The objective is to ensure that the book includes the most significant contributions to this area of knowledge. We also identify the most frequently cited authors and active research networks in this field. Additionally, we provide a comprehensive summary of driving cycles constructed in various regions worldwide, highlighting the data collection techniques and primary construction methods employed.

2.1 Systematic Literature Review

The most recent comprenhensive literature review on DC construction methods was published over a decade ago [1], with additional reviews available in [2, 3]. To ensure the value of documenting each decision made during the review process and to make the results both useful and replicable [4], the systematic literature review methodology illustrated in Fig. 2.1 was adopted, based on the approaches detailed in [5–7].

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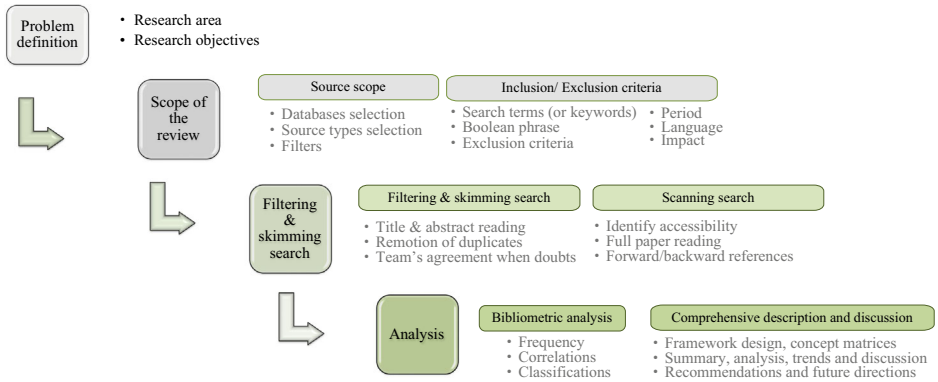

Fig. 2.1 Description of the methodology employed in this study for conducting the systematic literature review on driving patterns and DCs

The first stage of the systematic literature review is the "problem definition." In this case, the methodologies to describe driving patterns and construct driving patterns. Then, the scope of the literature review is defined. In this case, it encompassed the following considerations:

- The search was limited to the Scopus and Web of Science (WoS) databases.
- The Boolean phrase used was: ("Driving cycles" OR "driving cycle" OR "operation cycle" OR "driving pattern" OR "driving patterns") AND (develop* OR construct* OR build* OR synthesis OR framework OR select* OR generat* OR detect* OR comput* OR predict* OR optim* OR estimat* OR evaluat*) AND (typical OR representat* OR real-world OR city OR cities OR region* OR vehicle* OR bus* OR truck* OR motorcycle* OR electric* OR road* OR hybrid*). The first conjunction sentence was looked at in titles, and the last two were in Topics for WoS and ABS-TIT-KW for Scopus).
- A period between January 2005 and November 2023 was considered.
- Only published articles and proceedings in the English language were included.

Following the searching and filtering stage, from 867 results from Scopus and 321 from WoS, there were 859 different documents (set A in Fig. 2.2a). We removed duplicates of the same article in both databases (i.e., same authors with a related publication in more than one source. e.g., the first paper is in proceedings and the second in a journal. In these cases, for example, we kept the journal version).