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Stuck in the driver's seat: a conceptualisation for understanding car dependence and its determinants

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ABSTRACT

Car dependence brings along many negative social and environmental externalities that policymakers and stakeholders need to consider. Nonetheless, the concept is not well defined and lacks a clear framework regarding its determinants and mechanisms, which also leads to problems in terms of its operationalisation. Therefore, this paper proposes a conceptualisation and operationalisation of car dependence, which can serve as a basis for further research and policy. We define car dependence as the extent to which an individual is incapable to participate in location-based activities without a car in a satisfactory way. This definition is based on the theoretical background of the capabilities approach and the concept of motility and also linked to the concept of accessibility. Our conceptual model consists of seven components, most of which have been considered separately in previous conceptualisations, namely the land use system, transport system, natural environment, temporal component, social environment, and individual objective/subjective characteristics. These components range from being external to the individual (e.g. the land use system) to internal (e.g. individual features). Considering these components jointly emphasises the importance of looking at car dependence in a holistic, unifying way. This approach contributes to a better understanding of car dependence that goes beyond the explicit analysis of components in previous research. In addition, we provide a systematic approach to operationalising car dependence that contributes to a more comparable approach to measuring car dependence. Researchers have to decide whether they want to examine car dependence via its components or via self-report by individuals, whether they want to study the full set of components or only a subset, and whether they want to consider perceptions or factual information about external components. Therefore, our conceptualisation and operationalisation provide valuable new insights into car dependence regarding new research directions and policy approaches.

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1. Introduction

Cars are responsible for 45.6% of the transport sector's CO_2 emissions and 14.4% of the total emissions in the European Union (European Commission, 2022). While all other sectors have reduced their emissions substantially since 1990, the transport sector still produced more emissions in 2020 than 30 years before (European Commission, 2022). In addition, accessibility issues, in combination with social exclusion and health impacts, are major concerns from a societal perspective (Martens, 2016; Merom et al., 2018). Car dependence and a car-oriented transport & land use development, in general, are a significant cause for these developments (Newman & Kenworthy, 2015). Therefore, counteracting car dependence may be crucial to reducing overall CO_2 emissions and these social issues.

Research has extensively examined the concept of car dependence since it was first debated as automobile dependence (Newman & Kenworthy, 1989). Knowledge of its social and environmental ramifications and drivers is essential for transport policy and research, which has heightened the need to understand the components of car dependence in more detail. However, the existing discussion on car dependence is hampered by three crucial issues related to car dependence. First, there is no consensus on the definition of car dependence (Mattioli et al., 2016; Saeidizand et al., 2022; Sierra Muñoz et al., 2024). While some authors equate car dependence with car use and ownership (e.g. Newman & Kenworthy, 1989; Saeidizand et al., 2022), others define the concept based on the lack of mode alternatives and the resulting lack of choice (e.g. Blandin et al., 2024; Gray et al., 2001). Second, there is an ongoing discussion about the proper perspective to examine and conceptualise car dependence. Past research has primarily focussed on either the individual level or the society as a whole (e.g. Langer et al., 2023; von Behren et al., 2018), while fewer studies highlight the importance of a practice-based approach focussing on the extent to which specific practices and activities are (not) car-dependent (e.g. Mattioli et al., 2016; Van Eenoo & Boussauw, 2023). Generally, each of these conceptualisations considers its own set of components of car dependence without a joint consideration. Third, transport research increasingly considers subjective factors, such as perceptions, but only to a limited extent on car dependence (e.g. Van Eenoo et al., 2022; von Behren et al., 2018). Moreover, existing research does not provide a basic conceptualisation of perceived car dependence (also referred to as subjective car dependence). All three issues lead to the concept of car dependence being somewhat ambiguous.

Therefore, this paper aims to develop a conceptualisation and operationalisation of car dependence. We will establish an explicit definition of car dependence and develop a unifying conceptual model, which serves as a basis for implementing subjective components in car dependence research. Developing this conceptualisation and operationalisation will provide the foundation for further research discussions. Moreover, it will provide new insights and knowledge for future policies contributing to the reduction of social externalities and the modal shift from cars to alternative transport modes, which will help to counteract the negative environmental impacts in the transport sector.

This paper is structured as follows: The next section presents the crucial concepts laying the foundation for our conceptualisation. Section 3 presents a scoping literature review to clarify existing definitions, conceptualisations, and operationalisations of car

dependence. In Section 4, we summarise the main implications of the theoretical background for our conceptual model, which is presented in Section 5. Section 6 elaborates on further conceptual elements that are vital in understanding car dependence but are excluded from the model due to reasons of simplicity. Section 7 discusses how our conceptual model can be operationalised. In Section 8, we provide policy implications and a research agenda derived from our conceptual model. The final section concludes our main findings.

2. Theoretical background

Our definition and conceptualisation build upon the concepts of accessibility, capabilities, and motility. We introduce these concepts in the following paragraphs.

Car dependence relates to the concept of accessibility (e.g. Sierra Muñoz et al., 2024; Wiersma, 2020). It represents a form of an accessibility gap between cars and other transport modes (e.g. Langer et al., 2023; Wiersma, 2020). Hence, it is crucial to consider the concept of accessibility when discussing the concept of car dependence. Geurs and Van Wee (2004, p. 128) define accessibility as "the extent to which land-use and transport systems enable (groups of) individuals to reach activities or destinations using a (combination of) transport mode(s)". They conceptualise that accessibility has four components: land-use, transport, temporal, and individual components. Since accessibility and car dependence are related, these components also relate to car dependence.

Despite these different components, the current approaches to transport planning still emphasise the general role of the transport and land use system on accessibility levels of the population (Vecchio & Martens, 2021). Therefore, scholars have started to incorporate the capabilities approach as a framework to redirect the focus on the individual. This allows us to focus not only on the transport and land use system but also on how it affects individuals differently, taking into account heterogeneity between individuals regarding different personal features and desires (Vecchio & Martens, 2021), which can be crucial to examine concerning car dependence. In this approach, accessibility still plays a key role and is considered as the capability that represents "persons' possibility of engaging in a variety of out-of-home activities" (Martens, 2016, p. 137).

The capabilities approach was introduced by Sen (1985) and further developed by Nussbaum (e.g. Nussbaum & Sen, 1993). It focuses on "what people are effectively able to do and to be; that is, on their capabilities" (Robeyns, 2005, p. 94). The approach comprises five distinct elements: resources, conversion factors, capabilities, choices, and functionings (Vecchio & Martens, 2021). While resources represent external factors such as commodities and goods available to the individual (e.g. road infrastructure), conversion factors describe internal factors such as personal and social features that help the individual to appropriate the external resources (e.g. the ability to use the car). In contrast, capabilities represent the different freedoms available to the individual resulting from these resources and conversion factors. The individual chooses to act on one of these capabilities and transforms it into a functioning. The relationship between resources and conversion factors is very similar to the relationship between access and competence in the concept of motility, introduced by Kaufmann et al. (2004). In their conceptualisation, motility as the "capacity of entities (e.g. goods, information or persons) to be mobile" (Kaufmann et al., 2004, p. 750) involves two elements that function similarly: Access

describes the possible mobilities constrained by external options and conditions, and competence describes individual skills and abilities relating to access and appropriation. Both approaches show that it may be beneficial to not only focus on either external or internal components, but rather consider both external and internal factors when examining car dependence.

3. Overview of car dependence literature

The following sub-sections explore various developments in car dependence research, including of definitions, conceptualisations, and operationalisations. These developments serve as an important starting point for understanding the key determinants of car dependence and their interrelationships. This knowledge provides the basis for our definition and conceptualisation of car dependence. In Section 3.1, we first explain the methodology applied to detect existing literature.

3.1. Methodology

We applied a scoping review (Munn et al., 2018) to obtain an overview of existing car dependence literature and clarify the currently used definitions, conceptualisations, and operationalisations in the literature. The key criterion for inclusion of publications was a conceptual focus on car dependence; in other words, publications must discuss conceptual elements of car dependence. The search strategy was based on published journal papers with the following search string for all time on Scopus and Web of Science: TITLE ("car dependen*" OR "automobile dependen*") OR KEY ("car dependen*" OR "automobile dependen*"). We intentionally disregarded abstracts in our search approach to

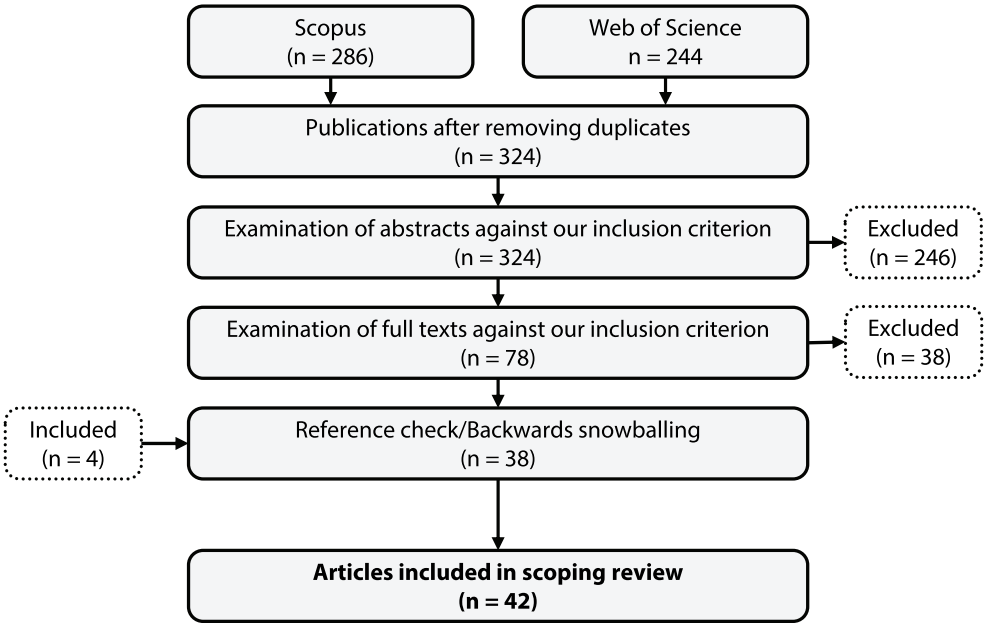

Figure 1. Scoping review process.

ensure we only detected papers focussing on car dependence as the central element. Figure 1 shows our scoping review methodology. Our initial search yielded 324 papers, after removing duplicates (n = 206). We read all abstracts and further removed 248 papers, which did not focus on car dependence and only mentioned the concept as a side aspect. The remaining 76 publications were read in full, and 38 papers were removed due to the lack of a conceptual focus on car dependence. Four publications were added after backwards snowballing from reference lists, as they met our inclusion criteria but did not appear in our initial search. Thus, we ultimately considered 42 papers in the review (Supplement 1). For a more extensive, systemic literature review of car dependence, we refer to Sierra Muñoz et al. (2024).

3.2. Definitions

Multiple academics have noted that different definitions and understandings of car dependence exist and that the concept has no precise boundaries (e.g. Gorham, 2002; Sierra Muñoz et al., 2024). While some researchers explicitly define car dependence (e.g. Weir et al., 2024; Wiersma et al., 2016; Zhang, 2006), others imply a definition that only becomes evident from the use of a synonymous use of car use or ownership or a subsequent operationalisation (e.g. Wang et al., 2021). There are two main strands of definitions.

One strand bases the definition of car dependence on its consequences. Historically, the definition was based on a combination of high car use, high gasoline consumption, and the dominance of the private car in the modal share (e.g. Litman, 2002; Litman & Laube, 2002). More recently, research has underscored this understanding by considering car use and ownership as proxies for car dependence (e.g. Asgari & Jin, 2023; Saeidizand et al., 2022). However, it has long been recognised that high car use and ownership do not automatically imply car dependence since both use and ownership may also be a matter of preference rather than necessity (Gorham, 2002; Wiersma et al., 2017). Moreover, high car dependence does not automatically imply high car use or ownership since individuals might be unable to afford either or might prioritise other things. Thus, car use and ownership are somewhat related to car dependence but cannot be used as synonyms, especially not as definitions for the concept.

The second strand defines car dependence as the lack of transport mode alternatives (e.g. Gray et al., 2001; Siedentop et al., 2013; Wiersma et al., 2021). When an individual suffers from a lack of adequate alternatives to the car (e.g. no access to other modes, inability to carry objects without the car, opportunities only accessible by car due to their location in the spatial environment), they suffer from what Brindle (2003) describes as a lack of choice, i.e. car dependence. The car becomes the only option in the individual's transport mode choice set (Zhang, 2006). This definition of car dependence is strongly linked to the accessibility by car and other modes (Wiersma, 2020).

3.3. Conceptualisations

Existing literature has tried to distinguish the different conceptualisations of car dependence (e.g. Gorham, 2002; Jeekel, 2013; Lucas & Jones, 2009). Mattioli et al. (2016) developed a summary typology from this research and distinguished three conceptualisations,

representing different perspectives on car dependence and their various components: (a) the macro-level, (b) the meso-level, and (c) the micro-level (Mattioli et al., 2016).

First, the macro-level perspective conceptualises car dependence as an attribute of societies. This perspective highlights external components leading to car dependence. These "structural constraints" (Jones, 2011, p. 48) refer to the existing land use and transport systems as key elements of car dependence, which primarily include transport service provision (e.g. operating hours, quality of service) and the location of amenities and activity opportunities. In contrast, the macro-level perspective disregards individual components and, therefore, individual heterogeneity within the society since the focus is on the external components that are equal to everyone (Mattioli et al., 2016).

Second, the meso-level pursues a practice-based approach, conceptualising car dependence as an attribute of practices. Research in this strand draws on Social Practice Theory (see Shove et al. (2012) for extensive discussion) and examines the elements of material, competence, and meaning to understand the relationship between specific practices and car use. Practice and activity components play an essential role in this context. Components of car dependence in this strand may be carrying people or objects, not being able to use other modes for a practice due to lack of competencies, and timing issues regarding trip chaining (Van Eenoo & Boussauw, 2023). Household structure plays an important role in these regards, as the existence of children or elderly in the household may result in escort activities.

Third, the micro-level conceptualises car dependence as an attribute of individuals. This research focuses on the diverse individual components that may influence car dependence. Individual components represent all the individual features that may influence the level of car dependence. These range from rather hard components, such as a disability and subsequent incapability of using other transport modes, to relatively soft components, such as attitudes towards or the perceived social meaning of the car (Gorham, 2002; Mattioli et al., 2016). They also include household characteristics such as household structure, but the primary focus remains on the number of adults and existence of children in the household (Asgari & Jin, 2023). Moreover, research pursuing this approach sometimes also includes perceptions of autonomy without the car and experiences with the car (e.g. Cairns et al., 2014; von Behren et al., 2018).

Each conceptualisation considers a specific perspective on car dependence with a specific set of components. For instance, while the macro-level looks at car dependence on a societal level with the external components (i.e. land use and transport system) as primary components, the micro-level considers the individual with individual-specific internal components as the main elements of car dependence.

3.4. Operationalisations

Studies have operationalised car dependence differently. The first approach measures the individual perception of dependence as a latent construct of statements. In other words, respondents indicate whether they feel dependent on the car, whether it would be difficult for them to adjust their lifestyle to being without a car, or how convenient a life without a car would be (Sohn & Yun, 2009; von Behren et al., 2018). This helps to understand how dependent individuals feel, but it may be beneficial to link them to factual information to understand how these perceptions arise (Sierra Muñoz et al., 2024).

Other approaches focus on the measurement of components and often reflect the differences in definitions and conceptualisations. In other words, these operationalisations depend on the definition of car dependence and its conceptual understanding.

In research defining car dependence as car use and ownership, studies use absolute car use, car modal share, as well as car ownership and motorisation rates as indicators of car dependence (e.g. Asgari & Jin, 2023; Saeidizand et al., 2022). Depending on the conceptualisations, these approximations are measured on the corresponding level. For example, car dependence at the individual level is measured as individual car use or ownership. In our eyes, this is not a valid operationalisation, since car use and ownership may also be a matter of preference and attitudes (Steg, 2005; Wiersma et al., 2021), and thus do not necessarily follow from car dependence.

In research defining car ownership by lack of alternatives, different indicators are used to measure this. On the macro-level, a significant strand of research examines accessibility as a crucial indicator, focusing on the land use and transport system to measure car dependence (e.g. Dashtestaninejad et al., 2023). Travel times compared to other modes play an important role, as well as the destination types (e.g. Langer et al., 2023; Wiersma et al., 2016). On the micro-level, components such as disabilities and pro-car attitudes are used as indicators to measure car dependence. In contrast to the focus on car use and ownership, this approach emphasises the lack of alternatives and highlights the role of dependence in the concept, which is of crucial importance.

Only few studies try to combine different conceptualisations. The approaches start from one conceptualisation, e.g. the individual perspective, and additionally include components from the other conceptualisations. For example, Alsabbagh (2024) and von Behren et al. (2018) both use components from all three conceptualisations (e.g. time savings by alternative modes, multimodality of the individual, and chauffeuring of children) to measure the level of car dependence. Their operationalisations highlight the additional value of a joint consideration of all the components. However, these are not (clearly) connected to an extensive conceptual model of car dependence.

In sum, current research generally does not provide a concise understanding of car dependence and its determinants. This lack of conceptual clarity arises from different definitions of car dependence and various conceptual and operational perspectives, which inhibit productive and comprehensive discussions on the concept. Therefore, it is essential to establish a unified definitional, conceptual, and operational framework for studying and understanding car dependence. This framework will be presented in the following sections.

4. Implications for understanding car dependence

Previous conceptualisations of car dependence have mostly looked at the concept of car dependence from one specific perspective, e.g. they solely considered external components such as the built environment. In contrast, both the capabilities approach and the concept of motility show a relation between external components (e.g. the transport system) and internal components (e.g. individual features). They place the individual and their features at the centre of the analysis while also considering components external to the individual and interactions between external and internal components. We consider it essential for a holistic conceptualisation and understanding of car dependence to examine the concept by joining the different perspectives into one unifying perspective to allow for

joint considerations of components of car dependence. With this, we focus on the capability of participating in location-based activities as the central element of car dependence. One can only participate in location-based activities when external and internal components make this possible. In the case of car dependence, this capability is only available with the car and not without it. However, it is essential to note that capabilities have a gradual character and are not dichotomous. In other words, there is a gradual state of car dependence and not just a differentiation between car-dependent and not car-dependent (Goodwin, 1995; Mattioli et al., 2016). Therefore, our definition of car dependence is:

> *Car dependence is the extent to which an individual is incapable of participating in location-based activities without the car in a satisfactory way.*

This incapability can result from two different causes. First, external components might facilitate the use of the car, but inhibit the use of other transport modes, making the individual less capable of participating without the car. Second, internal components (such as having a driver license or specific attitudes) might do the same either directly, or as moderators of external factors (see Section 5.4.3).

The term "in a satisfactory way" refers to both the satisfaction with the capability as well as with the participation. First, satisfaction with the capability relates to how this capability emerges. Individuals might be capable to participate without the car, but they still might be dissatisfied with how they are capable (e.g. longer journey times). Second, satisfaction with the participation relates to how the actual participation looks like. Individuals might be capable to participate in a particular activity, but they still might be dissatisfied with this participation (e.g. not the preferred activity or activity location). Similarly, individuals might not participate in an activity, but might still be satisfied since they do not want to participate in this activity. This has important implications, as we do not consider individuals car-dependent regarding activities that they do not want to participate in whether they can or not.

5. Conceptual model

Figure 2 shows our conceptual model of car dependence. This model depicts car dependence on a disaggregated level, putting the individual in the centre of the analysis. We differentiate between three primary elements: an internal sphere, an external sphere, and car dependence itself. Components are sub-elements and either allocated in one of the spheres or within both spheres. The following subsections will first present the different elements and components and then discuss the dominant effects between them.

5.1. Components in the internal sphere

The internal sphere consists of components that are specific to each individual. These internal components are very similar to what Vecchio and Martens (2021) consider conversion factors and Kaufmann et al. (2004) understand as competencies. All these factors help individuals to use other components that are external to the individual. Pot et al. (2023) distinguish features that are directly observable and features that are more subjective to the individual. Thus, there are two kinds of individual components: objective and subjective.

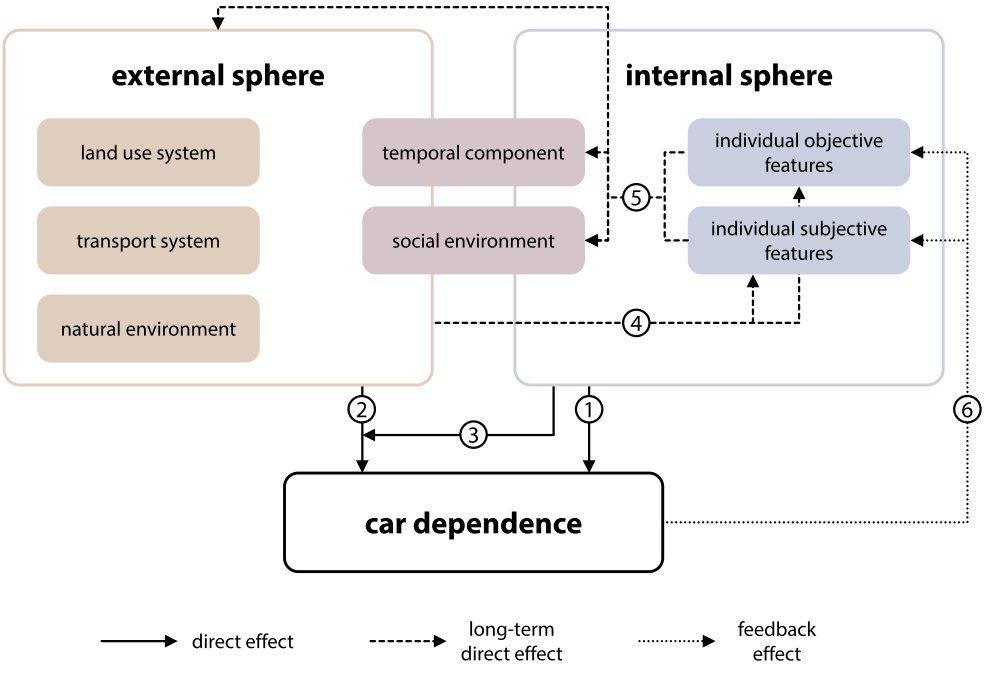

Figure 2. Conceptual model of car dependence.

5.1.1. Individual objective features

The objective component includes socio-economic characteristics (e.g. age and income), the presence of a physical or mental disability, and mobility means (e.g. possession of a public transport ticket or a bike). These factors represent an individual's needs and abilities, which directly impact the individual's capability to participate without the car (Pot et al., 2023).

5.1.2. Individual subjective features

The subjective component includes but is not limited to personal norms, perceived social norms, perceived security, and preferences for and attitudes towards specific transport modes. We later distinguish between factors that impact the capability more directly and factors that rather moderate the effects of external components. For instance, low perceived security using public transport at night represents a direct factor of car dependence because it can directly influence the capability to participate in location-based activities. In contrast, a negative attitude towards public transport use might not make a person incapable of using public transport but moderate the effects of external components.

5.2. Components in the external sphere

Some components are external to the individual. These are similar to what Vecchio and Martens (2021) consider resources and Kaufmann et al. (2004) understand as materials. They consist of the land use system, the transport system, and the natural environment.

5.2.1. Land use system

The land use system consists primarily of the spatial distribution, the characteristics of activity opportunities, and the residential location of the individual. In addition to the evident importance of the spatial location of activities, the characteristics of these activity opportunities are important as they determine their quality and what is necessary to perform them. For example, it may be necessary to bring specific sports equipment to participate in sports events. Similarly, it is necessary to be able to carry groceries when going to the supermarket. These activity opportunity characteristics are key in evaluating car dependence and play an essential role in the practice-based approach to car dependence (e.g. Mattioli et al., 2016; Van Eenoo & Boussauw, 2023). In our conceptualisation, residential location is part of the external components because it is relatively fixed for an individual at one point in time. However, it may become more flexible over time (Section 5.4.5).

5.2.2. Transport system

The transport system determines the availability of all transport modes and their characteristics. On the one hand, it includes the hardware, such as infrastructure for different modes, such as road, rail, bike, and pedestrian infrastructure, as well as the vehicles. On the other hand, it consists of the software, such as the actual supply of public transport, speed limits for road vehicles, and sharing offers and their characteristics, such as quality of service, reliability, and safety. Another critical factor in this regard are the costs of these transport options, as these determine whether individuals can afford them.

5.2.3. Natural environment

The natural environment includes topological conditions, seasonal effects, and weather conditions. Topology plays a vital role in the use of active travel modes. For example, altitude differences between locations increase the effort needed to bike. Similarly, seasonal effects and related weather conditions may also impact the possibility and convenience of some transport modes (Alsabbagh, 2024).

5.3. Components in both the internal and external sphere

Two elements, namely the temporal component and social environment, are present in both the internal and external spheres as they cannot easily be separated into internal and external parts. While this differentiation is evident in some cases, drawing a line is not always easy.

5.3.1. Temporal component

The car is often labelled as a "time saving device" (Kent, 2014, p. 103) and used to be able to participate in many activities within a tight activity schedule. This characteristic of the car relates to the concept of accessibility, in which the temporal component and temporal constraints play a vital role (Geurs & Van Wee, 2004). Therefore, the temporal component includes crucial factors in the analysis of car dependence.

This component consists of all temporal constraints affecting the individual capability to participate. We can categorise the constraints into four dimensions, primarily based on the capability, coupling and authority constraints introduced by Hägerstrand (1970). First, individual constraints refer to the basic human needs and the resulting available time

specific to each individual. In this case, basic human needs include but are not limited to the necessary sleeping hours, time spent eating, and personal care. Hägerstrand (1970, p. 12) emphasised the role of these individual constraints concerning what he called "capability constraints". These needs constrain the time available to an individual. Second, activity constraints comprise the time that an activity takes. These have a similar meaning as coupling constraints and define how long an individual "has to join other individuals, tools, and materials to produce, consume, and transact" (Hägerstrand, 1970, p. 14). While some activities may be more fixed (e.g. working hours), others are more flexible regarding duration (e.g. jogging). Third, institutional constraints represent the availability of opportunities at different times. For example, the opening hours of a supermarket determine when one can shop for groceries. Fourth, the transport system may predetermine fixed timeframes in which transport modes can be used. For instance, public transport might not be available in the late evening. The institutional and transport constraints are similar to what (Hägerstrand, 1970) depicts as authority constraints.

Together, all these constraints influence an individual's capability to participate in location-based activities since they predetermine either the external or internal temporal guidelines. While some are external (e.g. opening hours) and some are internal (e.g. sleeping hours), other constraints may be located somewhere in between (e.g. time it takes to go shopping).

5.3.2. Social environment

The social environment and social factors play a key role in car use and activity participation (e.g. Puhe, 2024; Soza-Parra & Cats, 2024). For example, social networks or social norms can foster or inhibit the individual capability to participate, resulting in an increased or decreased car dependence. However, existing research does not extensively discuss the social environment, as it does not go beyond the inclusion of household structure and activities such as care-taking and escorting children.

The first external factor is the location of the social environment, in other words, where one's friends and family live. These locations represent the social, physical environment as potential activity locations to which someone may travel. Subjective norms (i.e. descriptive and injunctive) represent a second set of factors that are more internal, as they depend on their interpretation. While these norms are external to the individual, their perception (i.e. perceived social norms) is an internal process. Descriptive norms determine how much a specific behaviour is considered typical or normal. In contrast, injunctive norms determine how much the social environment urges an individual to perform a specific behaviour (Hagger et al., 2018). A third aspect is social responsibilities and opportunities. While responsibilities (e.g. taking care of and escorting children) constrain individual capabilities, opportunities increase these capabilities because the social environment can enable certain things (e.g. parents help children to get to further activities by car).

5.4. Relationship between the components

The following section discusses the dominant effects between the components in our conceptual model (Figure 2). Dominant effects are labelled as such when existing research has emphasised their role in car dependence or when the effect intuitively seems

dominant. We do not discuss effects within the external sphere (e.g. land use and transport interaction) since our conceptual model depicts car dependence on a disaggregated level.

5.4.1. Direct effects of internal components on car dependence (1)

Internal components directly influence the capability to participate in location-based activities without the car, in other words, car dependence. For instance, individual features such as an inability to cycle directly affect car dependence. Similarly, a tight and more complex activity schedule and the need to escort children as a social obligation influence car dependence directly (Mattioli et al., 2016; Thorhauge et al., 2020).

5.4.2. Direct effects of external components on car dependence (2)

External components also have a direct effect on car dependence. If no public transport is available in a specific area, this directly constrains the capability to participate in activities without a car, regardless of internal components. In the same way, the activity of purchasing new furniture may also involve bringing the furniture home, which is difficult without a car (except for delivery); hence, this is also a characteristic directly affecting car dependence.

5.4.3. Moderation effects of internal components on external effects on car dependence (3)

Internal components can also moderate external effects. Vecchio and Martens (2021) refer to this as converting resources into capabilities. For instance, a missing public transport service in the late evening may influence the capability to participate in location-based activities, but only if the individual activity schedule includes late-night activities. Similarly, many close activities reachable by bike may positively influence the capability to participate without a car. However, if the individual has a negative attitude towards riding the bike, this may attenuate this positive effect.

5.4.4. Long-term direct effects from the external sphere on individual features (4)

External components influence individual features over time. In other words, individuals may adapt their attitudes and preferences to the external components to limit cognitive dissonance, c.f. reverse causality hypothesis (Van de Coevering et al., 2021). Living in an auto-centric neighbourhood with a high level of car dependence may result in an individual developing a more positive attitude towards the car. This effect relates to travel mode consonance and dissonance, which we will discuss in Section 6.3.

5.4.5. Long-term direct effects from individual features on the temporal components, social environment, and external sphere (5)

Individual features influence external and in-between components over time. An increasing reluctance towards the private car may lead to a change in the residential, work or fixed-activity location (e.g. residential self-selection hypothesis; Van de Coevering et al., 2021), which would then influence the available transport system, natural environment, temporal component, and social environment of the individual. For instance, a change to a closer working location may result in a change of temporal constraints that may decrease car dependence and allow for the use of other transport modes to travel to work.

5.4.6. Feedback effects from car dependence on individual features (6)

Car dependence influences individual features over time. When car dependence initially leads to car ownership and high car use, over time the ability to use the car may increase, while the ability to use other modes may decrease. Over time, this effect may also lead to increased car dependence. Lucas and Jones (2009) describe this habituation of the car as the process of car dependence that intensifies over time. This process begins with purchasing a car, continues with becoming habituated to car use and becoming more and more car-dependent. This phenomenon is also called the cycle of car dependence, in which individuals become "victims" of the car (Gorham, 2002, p. 109). Another example of this feedback mechanism relates to the attitude towards the car. If an individual has positive or negative experiences with driving, these experiences might change its attitude towards the car. Therefore, experiences with the car can lead to increasing or decreasing car dependence. The strength of the effects always depends on the level of car dependence. At lower levels, individuals might still be able to participate in activities with other modes, further gaining experiences and abilities with these modes. At higher levels, individuals might only be able to travel by car, lacking the possibility to gain experiences and abilities with other modes.

6. Further conceptual elements

In this section, we discuss further conceptual elements, including needs and wants, perceptions, and travel mode con-/dissonance. These elements are part of our conceptualisation, but not included in the model to increase its comprehensibility and simplicity, and reduce the risk of overcomplicating. Although we consider these the most important regarding our conceptualisation, this list is non-exhaustive and other elements may also play a role in car dependence.

6.1. Needs and wants

An important element, which we have not discussed yet, is the differentiation between needs and wants concerning car dependence; more precisely, the difference between the capability to participate in location-based activities that are necessary (need) and those that are unnecessary but desirable for the individual (want). While working or grocery shopping is necessary, watching a movie in the cinema or eating in a restaurant is more of a desirable activity. A crucial question is whether we only consider the necessary activities in car dependence research in order to evaluate car dependence from a social perspective or whether we consider both necessary and unnecessary activities in order to gain a picture of car dependence in a broader sense. This decision is aggravated by the fact that it is difficult to draw a line between necessary and unnecessary activities. While one might consider an activity necessary, another individual might not. The same applies to the location of activities. While working itself may be necessary, a specific work location is not. These questions demonstrate the gradual character of needs and wants and the difficulty of drawing a line.

Needs and wants may also refer to the actual capability to participate without the car, in other words, the conditions of participation. While individuals have different opinions towards which activities they want to participate in, they also have different opinions

about the conditions under which they want to be capable of participating. While researchers or policymakers can set need-oriented thresholds that determine when a person can participate (e.g. when a trip by public transport is less than twice the time by car), we also have to consider how capable or dependent a person wants to be. Individuals might consider a different threshold adequate regarding their actual wants and desires of capability.

6.2. Perceptions

Perceptions of the physical environment and, therefore, perceptions of car dependence may play a crucial role in our understanding of car dependence. Pot et al. (2021, p. 1) claim that "the relationship between the land use and transport systems and potential individual behaviour is mediated by how the environment is perceived". Since car dependence and the capability to participate strongly relate to potential travel behaviour and the land use and transport system, perceptions likely play an important role in car dependence. Similar to differences in how accessibility is calculated and perceived (Pot et al., 2023), there could also be differences in how car dependence is calculated and perceived. While an individual may not be very car-dependent based on the researchers' assessment of external factors, they may still perceive themselves as car-dependent, or vice versa. According to Pot et al. (2021), these mismatches between measurement and self-reported perceptions are based on either inaccuracies in awareness by the individual (e.g. lack of knowledge about external components) or inaccuracies in the measurement by the researcher (e.g. incorrect measurements of external components). For instance, an individual might perceive a walking trip to the grocery store longer than 30 min, although it is actually only 15 min based on the researcher's measurement. This difference has considerable implications for the resulting travel behaviour and its consequences.

Subjective internal factors, e.g. attitudes, preferences, and norms, may be crucial to perceptions of car dependence, as they may also influence how individuals perceive their external factors. For example, car users often underestimate distances since the effort of travelling is lower by car (Scerri & Attard, 2024). Therefore, considering these internal subjective features regarding perceptions of external components may be necessary to understand the mismatches between calculated and perceived levels of car dependence.

6.3. Travel mode con-/dissonance

Consonant travellers are individuals using their preferred transport mode, while dissonant travellers are not (Ma et al., 2021). Dissonance can lead to feelings of discomfort and dissatisfaction (Festinger, 1957). In the case of car dependence, it is important to distinguish between individuals whose preferred transport mode is the car and those whose is not. This is essential since individuals may not always consider car dependence negative since the car is their preferred transport mode. Therefore, they may prefer to travel by car or at least more than by other modes. This effect could go so far that some individuals may be voluntarily car-dependent. In contrast, other individuals may be car-dependent, although the car is not their preferred travel mode.

7. Operationalisation

The operationalisation of car dependence requires some crucial decisions to be made in advance. Figure 3 depicts these decisions within the operationalisation process. These play an important role in terms of how car dependence can be operationalised.

A fundamental decision is about the measurement item. While we can measure car dependence based on the components from our conceptualisation, we can also examine perceived car dependence based on self-reported levels of car dependence. While existing research has already used different statements to measure this perceived car dependence (e.g. Gauer et al., 2022), we suggest using statements that are linked to our definition of car dependence, for example:

(1) I am capable to participate in the activities I want without a car.
(2) Participating in activities at different places without using a car is easy for me.
(3) I find it difficult to get to work on time without using a car.
(4) For everyday tasks like shopping, it's hard for me to get by without a car.
(5) I find it difficult to manage family responsibilities without using a car.

These direct statements provide a direct and intuitive way to collect information on the individual perceived level of car dependence. They can be adapted to the activities and transport modes, which are considered important in the corresponding study. This approach can provide a more diversified picture of the activities and their levels of car dependence, which can then also be aggregated to a general level of car dependence.

If the aim is to measure the components of car dependence in order to examine car dependence, another decision is which components to include in the measurement. Previous operationalisations have tended to include a subset of the components from our conceptualisation, while ignoring others. However, our conceptualisation emphasises that it is beneficial to examine car dependence based on the full set of components to measure car dependence in its entirety. This does not mean that it is not possible to measure car dependence based on some components only. In particular, data on external

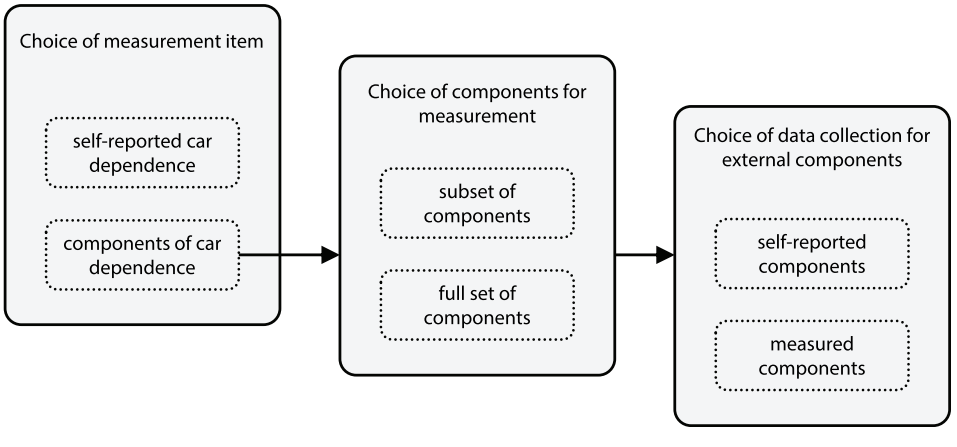

Figure 3. Decisions in the operationalisation process.

components (e.g. location of activity locations or transport-related data) are often publicly available and do not require separate data collection. Using these spatial data to measure a spatial level of car dependence can provide valuable insights, but it always needs to be emphasised that this spatial car dependence is only a partial picture of car dependence and does not take into account other important components. A related difficulty in this operationalisation approach is that external components are subject to perception and individuals may perceive them differently than they actually are (see section 6.2). Measuring these components without taking their perception into account could lead to different levels of car dependence than those perceived by individuals.

Therefore, if external components are included in the measurement, a final decision is whether to measure these components via spatial data or via self-report by the individuals. In the latter case, we can use statements to gather information about how the components are perceived.

All these operationalisation approaches and the corresponding decisions emphasise different measurements, which consequently affect the acquired information. For example, self-reported car dependence levels provide an insight into the individual perception of car dependence, while the measurement of components contributes to a better understanding of the determinants of car dependence, but only provides an indirect picture of car dependence. Combining the different approaches to operationalising car dependence may counteract this issue of partial explanation. Sierra Muñoz et al. (2024) also emphasise that perceptions of car dependence need to be linked to actual information on the components from spatial data. This combination of perceptions and actual information will contribute to a more detailed understanding of which components are more likely to be associated with higher levels of (perceived) car dependence.

8. Discussion

8.1. Policy implications

The need for policy action arises from the multiple social and environmental issues associated with car dependence. Our definition and conceptualisation state that car dependence and related accessibility issues can hinder an individual's capability to participate in location-based activities without a car. When an individual is unable to drive a car or does not have a car available, this dependence results in potential social exclusion due to the individual's inability to participate in certain activities (e.g. Martens, 2016). However, even if an individual is able to drive a car and has a car available, car dependence has serious social consequences in form of increased car-related costs (e.g. Belton Chevallier et al., 2018), as well as potential health impacts resulting from the exclusive use of the car and the absence of active travel modes (e.g. Merom et al., 2018). Additionally, increased car use and ownership driven by this dependence cause environmental consequences, such as increased emissions, congestion levels, negative impacts on road infrastructure, and the nuisance of driving and parked cars.

In the past, policymakers and stakeholders have mostly focused on improving transport infrastructure and the provision of public services in general (i.e. external components) to counter car dependence and its negative consequences. However, our

conceptualisation shows that car dependence goes beyond these external components and additionally includes other components, namely individual features, the temporal component, and the social environment. Therefore, policies would also need to go beyond measures such as improving public transport and additionally include measures aiming to impact these components of car dependence. For example, new policies could aim to reduce temporal constraints by extending the opening hours of shops or encourage the implementation of flexible working hours.

This shift in focus also involves the consideration of moderating effects between internal and external factors. Our conceptualisation highlights that internal factors moderate the influence of external factors. While improving public transport may be an effective measure for one population group, it may not be effective for other groups with different features (e.g. individuals with less knowledge about public transport schedules and ticket systems). Policymakers should consider this individual heterogeneity within the population in the development of policies, as this may significantly increase the policy's impact.

Another policy implication arises from distinguishing between needs and wants, specifically the difference between activities individuals need to participate in or those they simply want to. Focusing solely on necessary activities, such as grocery shopping or working, may offer a straightforward method for assessing car dependence. However, it is also crucial to consider unnecessary but desirable activities that go beyond basic services of general interest, as they can also contribute to dependence. Ignoring these latter activities might lead to underestimating car dependence, potentially influencing the related travel behaviour. Therefore, policymakers and researchers could consider all the desired activities of individuals, not just the necessary ones, to create a holistic picture of car dependence.

One final policy implication is the shift from a threshold-based evaluation of car dependence to an evaluation of perceptions of car dependence. While it may make sense to establish certain thresholds for car dependence – such as considering someone car-dependent if travelling by other modes takes more than twice as long as travelling by car – individuals may identify as car-dependent much earlier than this threshold suggests. Therefore, policymakers and researchers could adjust their thresholds to align with individual perceptions and evaluations.

8.2. Research agenda

In the following paragraphs, we will present a non-exhaustive list of potential research endeavours that could contribute to our new perspective and understanding of car dependence.

Our conceptual model includes several components overlooked or not considered in detail in previous research on car dependence: the natural environment, the temporal component, and the social environment. In addition, we divided the individual features into objective and subjective features to emphasise crucial differences within this component. One need for further research is the analysis of the effect of these components, which have not received much attention in previous research (with some exceptions, such as von Behren et al., 2018). This knowledge will contribute to an improved, holistic understanding of car dependence and its determinants.

A second research need is to examine the moderating effect of internal components on external effects. For example, while the availability of a nearby supermarket may reduce car dependence, internal factors such as old age (e.g. an older person who cannot carry goods even a short distance on foot) may reduce the magnitude of this effect on car dependence. Understanding this moderation provides new insights into the extent to which the external components, such as the land use system, do or do not influence all individuals similarly.

A third research need is to validate the operationalisation and measurement approaches to car dependence proposed in this paper. On the one hand, this relates to the measurement challenges. Crucial questions here are which statements are most appropriate for individuals to self-report their perceived car dependence and their perceptions of its components. Different statements may result in different measurement results. On the other hand, it refers to the discrepancies between the measurement approaches. Important questions are to what extent these approaches lead to different levels of car dependence and what constitutes these differences between the approaches. Existing research has already started to partially consider perceptions of car dependence (e.g. Van Eenoo et al., 2022; von Behren et al., 2018), but further research is needed to improve our understanding of the mismatches between measured and perceived car dependence and its components, and how these mismatches arise. Answering these questions can provide valuable insights into our understanding of car dependence and helps to increase the comparability of operationalisation approaches.

A final research need relates to feedback and long-term direct effects. Knowledge of the temporal dynamics of car dependence in terms of its influence on individual features and, indirectly, on external components will contribute to a better understanding of the cycle of car dependence (e.g. Gorham, 2002). In other words, it will help to understand how car dependence reinforces itself within individuals over time and provide insights into how this cycle can be broken to reduce car dependence. Analysing these feedback and long-term effects in our model will require longitudinal data collection to understand the causal links between the different components, such as external components and individual features.

9. Conclusion

This paper aimed to develop a comprehensive definition, conceptualisation, and operationalisation of car dependence and create a new conceptual basis for implementing subjective components. Our conceptualisation reveals that car dependence goes beyond the exclusive analysis of specific components, such as the built environment and activity characteristics. Instead, it necessitates a holistic and multifactorial perspective that considers the full range of components and their interrelationships. By adopting this new perspective, this paper offers valuable insights that can significantly enhance future research and inform policy interventions aimed at addressing car dependence more effectively.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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