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**Conference Paper**

## Convergent Digital Infrastructures and the Role of (Net-)Neutrality

28th European Regional Conference of the International Telecommunications Society (ITS): "Competition and Regulation in the Information Age", Passau, Germany, 30th July - 2nd August, 2017

**Provided in Cooperation with:**

International Telecommunications Society (ITS)

*Suggested Citation:* Sedlmeir, Joachim; Hopf, Stefan; Neuburger, Rahild; Picot, Arnold (2017) : Convergent Digital Infrastructures and the Role of (Net-)Neutrality, 28th European Regional Conference of the International Telecommunications Society (ITS): "Competition and Regulation in the Information Age", Passau, Germany, 30th July - 2nd August, 2017, International Telecommunications Society (ITS), Calgary

This Version is available at:

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# Convergent Digital Infrastructures and the Role of (Net-)Neutrality

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## Abstract

The integration of modern information and communication technologies (ICT) triggers an evolutionary process from previous analog towards convergent digital infrastructures that are the basis for new, cross-domain services and applications. The implementation, however, poses new requirements and regulatory challenges. Among these, a broader view on net neutrality appears to be a crucial precondition that exceeds the single focus on the non-discriminatory transmission of data via the proprietary telecommunication infrastructures of different network operators as critical gatekeepers. Rather, a new, systemic way of thinking in digital infrastructures is necessary. Hereby, the scope of neutrality expands to different functions on several levels of interconnected infrastructures in order to design interoperable systems as platforms for future-orientated, cross-domain services. To adequately describe and comprehend the trajectory from previous analog to convergent digital infrastructures that allow novel services via specific platforms and facilitate an interaction across various domains and industries, we introduce and illustrate distinctive evolutionary steps that reflect different levels of convergence. Since the complex interrelationships and interdependencies within convergent digital infrastructures cannot be readily analyzed in a holistic manner, this paper focuses on the mobility domain as primarily field of analysis. For the examination of digital mobility infrastructures in the context of neutrality, a case study-orientated approach has been developed that divides the field of analysis into three predefined levels and allows an investigation of the specific requirements to implement such convergent infrastructures from a technology-, data- and service-specific perspective. Based on this analysis, we define distinctive extensions to the existing view on net neutrality and, thereby, contribute to the already existing claims in academic literature for the conception of a more holistic view on this topic.

**Keywords:** Digital Infrastructures; (Net-)Neutrality; Convergence; Digital Mobility Services

## 1. Introduction

The provision of a general accessibility to infrastructures is regarded as a necessary precondition of economic development (Esfahani and Ramírez 2003, Florio 2013). The term “infrastructure”, however, is often misinterpreted (Henfridsson and Bygstad 2013, Tilson et al. 2010) as no generally accepted definition is existing (Frischmann 2012). Traditionally, infrastructures are often seen as public facilities (e.g. streets or railways as part of the traffic system; utilities like energy; the health care- and education system; or the public administration) that share the same typical physical and economic characteristics (Goldsmith 2015, p. 27): a) “*immobility*” as they are designed for a dedicated geography, b) “*longevity*” that refers to the time it takes to build the infrastructures, but also refers to the long time of usage, c) “*expensive*” due to the generally high costs of construction, operation and maintenance, and d) “*public service*”, emphasizing the high value for the community. As vital precondition for the economic and societal well-being and its status as public or common good (Samuelson 1954) that are often underestimated in value by individuals (as typical attribute of so called “*merit goods*”, cf. Musgrave 1959) infrastructures have ever been subject to regulatory interventions.

The ongoing process of digitizing – i.e. the integration of modern ICT, enabling the conversion of analog signals into bits (cf. Shapiro and Varian 1999) – is supposed to have massive consequences for previous analog infrastructures,<sup>1</sup> as it “has the potential to remove the tight couplings between information types and their storage, transmission, and processing technologies” (Tilson et al. 2010, p. 749). Based on the interconnection of digital devices embedded in previous analog infrastructures, an evolutionary process of convergence is triggered that ends in the transformation from digitized- towards digital infrastructures (Tilson et al. 2010) and opens the potential for a digital linkup of different digital infrastructures within a domain (e.g. between road- and railways in the mobility sector within the mobility domain) or across domains (e.g. between the mobility and health care domain). In other words, the integration of modern information and communication technologies leads to an massive disruption of the typical utility infrastructures – inter alia from the mobility, health care, education, energy, administration and communications domain – that enforces the convergence of these formerly separately managed an operated domains (AG 2 2012). As a consequence, this process of transformation is the basis for the emergence of novel functions, applications and services that

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<sup>1</sup> The societal and economic consequences, resulting from the process of digitization by the term “digitalization.”

will be built on such converging infrastructures and include autonomous operating, analyzing, information processing and -managing functions and components on different technological levels (Sedlmeir et al. 2015). This includes, e.g. the realization of smart factories in the context of “*industry 4.0*”, new forms of intelligent home networking in “*smart homes*”, holistic development concepts in “*smart cities*” as well as intelligent traffic control and planning systems of “*smart mobility*”-solutions.

According to an estimate by *Fraunhofer-ISI*, the economic potential that comes along with the realization or implementation of such *convergent digital infrastructures* as “*intelligent networks*”<sup>2</sup> and the products or services based upon (so called “*intelligent-*” or “*smart services*”, cf. acatech 2015b) is prognosticated alone for Germany in the period from 2012 to 2022 up to € 336 bn (BMW 2012). Beyond the achievement of pure gains in efficiency, the implementation of an intelligent interconnection of several domains also creates the preconditions for the development of novel, primary data-based business models (acatech 2014, 2015a) that, in turn, facilitate the entry of new actors and leads to disruptive changes within different fields of application. Moreover, the realization of *convergent digital infrastructures* and smart services is also aimed at making a significant contribution to handle the prevailing industrial or sociopolitical challenges, inter alia to overcome the demographic change in the health care sector, to implement the so called energy revolution in order to counteract the climatic change by an intelligent interconnection of energy generators and storages in “*smart grids*” (AG 2 2012), or – last but not least – to cope with the rapidly growing traffic volume by novel forms of interconnected traffic planning and management and -planning (i.e. in terms of “*smart mobility networks*”, cf. AG 2 2013). Here, by offering intermodal travelling solutions that include standardized identification- and payment systems, and by setting the necessary conditions for autonomous driving, a huge time-saving potential and improvements in travelling comfort are expected (Picot et al. 2014).

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<sup>2</sup> In accordance to the “*Forschungsverbund Intelligente Infrastrukturen und Netze*” – a research association to which the authors of this study belong to – “*Intelligent Networks*” can be defined as follows: “Following an evolutionary understanding, “Intelligent Networks” arise by connecting classical infrastructures and the supplementation of “intelligence” (understood as autonomously operating, analyzing, information processing and controlling functions and components on multiple levels) – i.e. modern transportation systems combine diverse ICT-HW/SW-function modules in order to achieve new features and innovative applications that generate excess value for the actors involved. Therefore, the “intelligence” of infrastructure is a dynamic, evolutionary, and multidimensional phenomenon, that enables novel services and applications both within (vertical convergence) and across the single domains (horizontal convergence)” (Picot et al. 2014, p. 19).

The enormous potential benefits, induced by the realization of such digital infrastructures or smart networks and their convergence (i.e. the connection of several domains and the development of cross-domain services), however, come along with new and complex requirements or challenges for their realization that – in the regulatory context - particularly concern the vivid debate on net neutrality<sup>3</sup> and exceed the claims for an adequate handling of the growing data streams, transmitted over the proprietary infrastructures of the network operators. Rather, a broader view on net neutrality, that goes far beyond a single focusing on the non-discriminatory transmission of data via the proprietary telecommunication infrastructures of network operators seems to be an essential precondition. In other words, the convergence of digital infrastructures decisively depends on the exchange of data and, therefore, requires a new, systemic way of thinking. Hereby, the scope of neutrality has to be expanded to different functions on several levels of interconnected (digital) infrastructures in order to design interoperable systems as platforms for future-orientated services (Picot et al. 2014, Sedlmeir et al. 2015).

In contrast to classical view on net neutrality that typically refers to Internet service provider (ISPs) as gatekeepers on the infrastructure level, it is also important to consider the critical gatekeepers that operate on the data- or service level that are in control of the referring platforms (see also Easley et al. 2016). The convergence of digital infrastructures, that decisively depends on a functioning and adequate exchange of data from partially heterogeneous sources, requires instead a new, systemic way of thinking that goes beyond focusing on the infrastructure level and takes the different functions of the economic actors on the different levels of digital infrastructures into account. Therefore, the following research question can be derived for this study:

RQ1: *What are the key-requirements in the evolutionary steps from initially analog towards digital infrastructures in the context of (net-)neutrality?*

RQ2: *Which implications can be derived for the conception of a more holistic view on (net-)neutrality?*

To adequately describe and comprehend the trajectory from previous analog to *convergent digital infrastructures* that allow novel services via specific platforms and facilitate an interaction across various domains or industries, we introduce and illustrate three distinctive

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<sup>3</sup> Also referred to as “*network neutrality*”.

evolutionary steps that reflect the different levels of convergence. Since the complex interrelationships and interdependencies within *convergent digital infrastructures* cannot be readily analyzed in a holistic manner, this paper focuses on the mobility domain as primarily field of analysis. As a consequence of its novelty and high practical relevance, this study on convergent digital (mobility-)infrastructures in the context of neutrality is based on a exploratory, case study-based approach. To account for the scope of the evolutionary steps towards *horizontally convergent digital infrastructures*, we divide the mobility domain into three predefined levels of analysis: the *micro-*, *meso-*, and *macro-*level. Moreover, our method allows an investigation of the neutrality-specific preconditions to implement convergent infrastructures from a *technology-*, *data-*, and *service-*specific perspective. Hence, this approach meets the requirements of a clear structure of the object of investigation and leads to the definition of distinctive extensions to the existing view on (net-)neutrality. Thereby, it contributes to the already existing claims in academic literature for the conception of a more holistic view on this topic.

By analyzing *convergent digital infrastructures* in the mobility domain on a *micro-*, *meso-*, and *macro-*level, we finally derive distinctive extensions to the concept of (net-)neutrality from a *technology-*, *data-*, and *service-*perspective. The scope of the discussion on *technology neutrality* exceeds the concept of *device neutrality* (Hahn et al. 2007), as differentiations between several forms of sensor or access networks, specific transmission standards, and the integration of various IT-modules (i.e., ICT-hardware in general) are also considered. The *data neutrality*, instead, refers to the principal non-discriminatory, ubiquitous data availability from heterogeneous sources, with special focus on the specific requirements on quality, (near-to) real-time usability and privacy- or security-relevant criteria. Last but not least, the changing relationships and interdependencies due to the entry of new data and service platforms, whose value chains can be modularly configured and assembled to network-based business models, is subsumed under the concept of *service neutrality*.

## **2. Theoretical Background**

### **2.1. Towards Convergent Digital Infrastructures – Definition and Stages of Evolution**

Although infrastructures are an essential precondition for the economic and societal prosperity in modern societies (Esfahani and Ramírez 2003, Florio 2013, Frischmann 2012, Goldsmith 2015) the economic literature offers no widely accepted definition (Picot et al. 2015). Moreover, the

academic discussion even shows examples for which the term *infrastructure* is used, but without explicitly dealing with it (Henfridsson and Bygstad 2013, Tilson et al. 2010). While Gramlich (1994) reviewed several interpretations, more recent studies on the taxonomy of infrastructures, however, are still not in agreement (Picot et al. 2015, Torrisi 2009). Following a broad perspective (Jochimsen 1966, p. 100), infrastructures can be regarded as “sum of material, institutional and personal facilities and data which are available to the economic agents and which contribute to realizing the equalization of the remuneration of comparable inputs in the case of a suitable allocation of resources, that is complete integration and maximum level of economic activities”. Depending on the specific characteristics, *tangible*, *intangible*, and *institutional* infrastructures<sup>4</sup> (Frischmann 2012) can be differentiated. Typical examples of tangible infrastructures are traffic systems, including streets and railways within the mobility domain, or utility infrastructures like energy, water, and communication networks. Intangible infrastructures, instead, include but are not limited to both education-, research-, health care- and social services systems, and endowments at the country or local level. Finally, institutional infrastructures are represented by legal, economic, and social systems, or – in a broader scope – cultures and traditions (Picot et al. 2015).

The ongoing process of digitization – i.e. the integration of modern ICT in previous analog, separately managed and operated infrastructures (no matter whether such infrastructures are of tangible, intangible, or institutional nature) triggers a transformation process, that ends in digital infrastructures which open the potential for an intra- (i.e. *vertical*) or cross-domain (i.e. *horizontal*) interconnection of different systems (Tilson et al. 2010). Moreover, this convergence of digital infrastructures is supposed to promote and enable the emergence of new functions, applications and services.

The convergence of the IT-, telecommunications- and media industry is a first example for *convergent digital infrastructures*. Accordingly, the usage of ICT and the interconnection via the Internet has led to the convergence of three formerly separate industries with extensive technical and economic consequences. Moreover, this convergence has induced disruptive changes to established and triggered the development of new, innovative business models (Hess 2006, Knieps and Vogelsang 2007, Zerdick et al. 2000). More specifically, the ongoing digitization

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<sup>4</sup> This differentiation reflects an ideal type of classifying infrastructures as even intangible- or institutional infrastructures include tangible components.

reinforced a structural coupling between various value chains of different markets. At first, this process resulted in a convergence of the telecommunications- and IT-sector and, in a second stage, facilitated the integration of the media industry that (in addition to the classical broadcasting infrastructures like terrestrial-, cable-, or satellite networks) increasingly used telephone or computer networks including the Internet for the transmission of content. The concept of *convergent digital infrastructures* is, however, not limited to an IT-based integration of one single (industry-)sector (like the media industry as described before) and the interconnection of different infrastructures within a single domain, but rather suggests an on-going and holistic convergence across various domains (e.g. the mobility-, energy-, health care-, administration-, education-, and communications sector) as part of an evolutionary process (BMW 2012). The expected scope and potential may be far greater in relation to the previous two stages of convergence between the IT-, telecommunications- and media sector, while for the next stages of convergence the complexity of defining and providing the necessary prerequisites for realizing such digital infrastructures is rising at the same time. Based on Picot et al. (2014) we introduce three generic, evolutionary stages in order to structure the evolutionary process of digital infrastructures. This trajectory from previous analog towards *digitized*, *vertically-* and *horizontally convergent digital infrastructures* is explained in Table 1 and in the paragraphs below.<sup>5</sup>

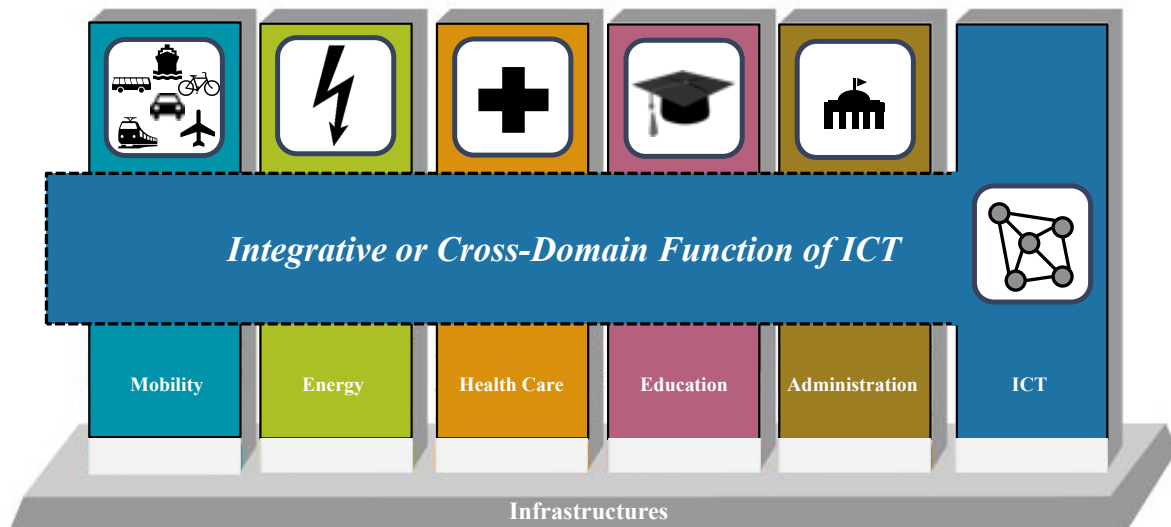
Evolutionary Step	Explanation	Example
<i>Digitized Infrastructures</i>	Enrichment of existing, previous analog infrastructures with domain-specific ICT-solutions (e.g. cyber-physical systems, sensors), enabling an interaction between the “real” and “virtual” world	Sensor-embedded roadways that digitally register the number of vehicles using a specific part of the road infrastructure
<i>Vertically Convergent Digital Infrastructures</i>	ICT-based integration of various infrastructures as (sub-)systems <i>within</i> a domain, resulting in the phenomenon of <i>vertical</i> convergence	Virtual interconnection of different means of transport and its underlying digital infrastructures, that enables intermodal travelling options, including standardized identification and billing methods
<i>Horizontally Convergent Digital Infrastructures</i>	ICT-based integration of various infrastructures as (sub-)systems <i>across</i> domains, resulting in the phenomenon of <i>horizontal</i> convergence	Smart cities, based on <i>horizontally converged digital infrastructures</i> that enable coordinated, cross-domain services, e.g. from the mobility-, energy-, health care-, and administration domain

**Table 1: Evolution Stages of Convergent Digital Infrastructures.**

<sup>5</sup> The following description of the evolutionary process towards *convergent digital infrastructures* is based on an approach, initially elaborated by the authors for a research project financed by the German Federal Ministry for Economic Affairs and Energy (cf. Picot et al. 2014).



In this evolutionary process, modern ICT is considered as crucial enabler for the resulting convergence. In other words, ICT is attributed with a fundamental integrative function that is the precondition for the realization of cross-domain applications or services based on *horizontally convergent digital infrastructures* (see Figure 1).



**Figure 1: Cross-Domain Function of ICT in Horizontally Convergent Digital Infrastructures (Own Illustration, based on Picot et al. 2014, p. 18).**

As already described and shown in the table above, the trajectory from analog and separately managed and operated infrastructures towards *horizontally convergent digital infrastructures* that enable integrated, cross-domain services, can be divided into three distinctive steps:

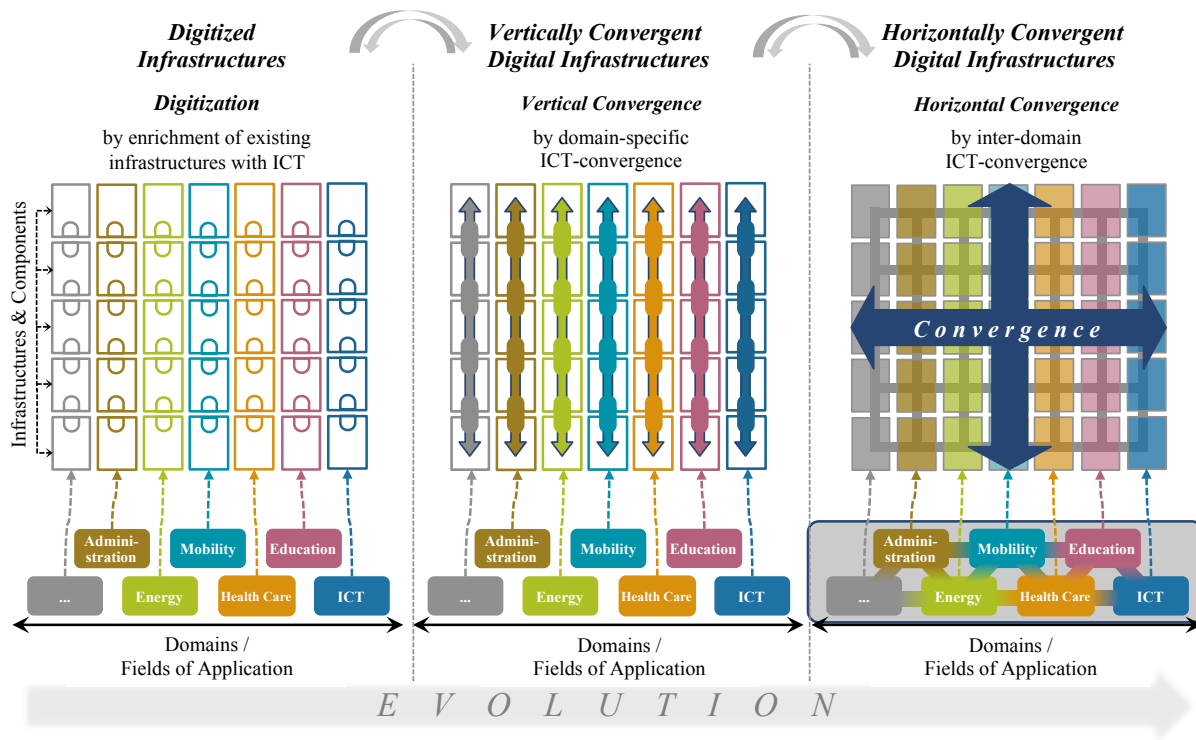
First, the enrichment of already existing (analog) infrastructures with domain-specific ICT-solutions results in *Digitized Infrastructures*. For the infrastructures of different domains this step is achieved, for instance, by integrating cyber-physical systems, sensors or technologies that enable the interaction between the physical and virtual world, based on the transformation of information from analog signals into an array of bits (cf. Shapiro and Varian 1999). In the context of the mobility-domain, for instance, sensor-embedded roadways that digitally register the number of vehicles that use a specific part of the road infrastructure could be an example for digitizing previous analog infrastructures. It is expected that in many domains this process of digitization has at least begun and or has even been completed (Picot et al. 2014).

The second step describes *vertically convergent digital infrastructures* that are realized by an ICT-induced, domain-specific (i.e. vertical or “within a domain”) convergence of infrastructures,

based on the integration of generic ICT-based functions. In the context of the mobility sector, for instance, the virtually connected and interoperable digitized infrastructure components of several means of transport enable the realization of intermodal travelling options, including standardized, comprehensive identification-, pricing-, and billing methods. While the first step of the evolutionary process has already been realized in most infrastructures, that seems not be the case for this second step that indicates a general domain-specific convergence.

Third, the final stage (for now) in the evolutionary process is characterized by unified services, based on *horizontally convergent digital infrastructures* that evolve in the course of cross-domain (i.e. horizontal) ICT-convergence. This means that on the basis of the interconnection, processing and smart combination of domain-specific data across different sectors and domains, novel services and applications are built on *convergent digital infrastructures* (i.e. so called “*smart services*” are emerging, cf. acatech 2015b). Moreover, this highest level of convergence is characterized by the formation of so called *meta-(infra)-structures* like “*smart cities*”, created on the basis of existing digital infrastructures, that virtually map emergent, overarching interdependencies or relationships and constitute a conceptually distinct domain (Picot et al. 2014, Sedlmeir et al. 2015). In turn, such smart cities, implemented on the basis of *horizontally converged digital infrastructures* facilitate coordinated, cross-domain services and applications (e.g. from the mobility, energy, health care or administration domain). Technically, such meta-structures, however, can only be realized in conjunction with a high degree of virtualization – particularly by leveraging software defined networking (SDN) capabilities. Following Picot et al. (2014, p. 20) it is assumed that the majority of new services for horizontal functions, new products and *meta-(infra)-structures* won’t come into existence before 2025.

Generally, it is important to note that this evolutionary process follows neither necessarily a linear nor deterministic path, but rather serves as a conceptual guideline. In other words, due to different preconditions, the evolutionary stages of digital infrastructure convergence will be achieved within the respective domains at different times. See Figure 2 for a graphical illustration of the evolutionary process from *digitized-* towards *horizontally convergent digital infrastructures* and the potential development of new, cross-domain applications and services.



**Figure 2: The Evolutionary Process Towards Horizontally Convergent Digital Infrastructures (Own Illustration).**

As already mentioned the potential, resulting from the convergence of digital infrastructures is manifold. In the field of mobility, for instance, *vertically convergent-* and *horizontally convergent digital infrastructures* are expected to enable inter alia the multimodal usage of transport services, an comprehensive optimization of traffic flow with less congestion, and an increase in road safety (Picot et al. 2014, p. 170ff.).<sup>6</sup> These services and applications entail, however, novel conceptual and technical requirements regarding the communication infrastructure (e.g. ubiquitous connectivity and interoperability as well as near to real-time communication) and the way data is transferred (esp. regarding the provision and processing of data from heterogeneous sources, while considering requirements on data protection and -security). In addition, the smart interconnection of different infrastructures in and across various domains fosters new market players (e.g. cross-domain operating data- and service platforms), thereby changing the competitive dynamics (Renda 2010, p. 8ff.) within the various sectors. In other words, new types of gatekeepers could emerge that have the control over data access or

<sup>6</sup> This is an consolidation of different potentials, based on an analysis of prospective developments in the mobility sector, see also Aberle and Hofmann (2012), acatech (2014), AG 2 (2012, 2013, 2014), Arthur D. Little (2014), Baums and Scott (2013), Böhm et al. (2012), Fishman (2012), Geisberger and Broy (2012), Münchner Kreis (2011).

could influence compatibility by setting standards for cross-domain applications on the basis of digital infrastructures. Thus, this development has also far-reaching consequences regarding the existing debate on net neutrality since services on *convergent digital infrastructures* might be subject to discrimination or exclusion depending on the economic interest of the actors involved. All in all, openness and a non-discriminatory treatment of the cross-infrastructure data transfer and the services based upon might turn out to be an critical issue for the innovative development of digital infrastructures.

By now, studies that explicitly analyze net neutrality in the context of *convergent digital infrastructures* and their smart interconnection do not exist. Between a generally neutral transfer of data on the one side and the need for reasonable network management practices in order to guarantee the distinctive *quality-of-service (QoS)* for enabling (time-)sensitive services (e.g. traffic control- or health care- and emergency services), an area of tension emerges, however, that has to be analyzed.

## **2.2. (Net-)Neutrality and Convergent Digital Infrastructures**

Despite the persistent and intensive public debate on a non-discriminatory transfer of data over the Internet, the concept of net neutrality continues to be regarded as an abstract phenomenon with inconsistent interpretations across different perspectives or disciplines (Reicher 2011, Shin 2014). This means that from a technical, economic, legal and regulatory perspective, there exists a controversial, complex and multifaceted discourse on this subject (Noam 2011, Sahel 2011, Síthigh 2011, White 2014). Reicher (2011, p. 733) draws the conclusion that net neutrality is generally one of the least understood concepts in the Internet policy.

As a consequence, the different attitudes and interpretations in the context of net neutrality are reflected in a disagreement on a generally accepted definition (Marcus et al. 2011, Null 2011, Picot and Krcmar 2011, Strover 2010, van Schewick 2010, 2015). Based on his seminal article “*Network Neutrality, Broadband Discrimination*”, Tim Wu (2003) is regarded as the originator of the concept of net neutrality<sup>7</sup>. According to him (cf. Wu 2003, p. 145), net neutrality does not allow any prioritization of specific applications over others (e.g. video streaming over email).

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<sup>7</sup> Apart from this, statements can be found in literature that significantly predate the advent of the debate on network neutrality: “Contrary to the popular notion that the idea of ‘neutrality’ first appeared in 2002, the article traces the term back to the 1960s when the Federal Communications Commission took up the problem of convergence or ‘communications’ in the Computer Inquiry proceedings” (Lentz 2013, p. 568). Moreover, according to Krämer et al. (2013) the origins of net neutrality are often seen in the open Internet movement based on Lawrence Lessig (2001).

Consequently, the equality of data transported by network operators – regardless of the respective content or application – shall guarantee a fair competition between providers of services and applications (see also van Schewick 2007). Therefore, considerations to oblige network operators to an equal treatment in order to prevent distortive discrimination emerged (cf. Grove and Agic 2012).

According to Vogelsang (2007, p. 220), generally two variants of defining net neutrality can be differentiated: While in an a) extreme interpretation<sup>8</sup> a strict equality of treatment of all bits across the Internet is postulated, “regardless of content, platform, origin, destination or type of the service” or application and, therefore, without any censorship, discrimination or prioritizing, a b) moderate understanding of net neutrality postulates the “network-based equality of competition between content and service providers in the broadest sense” (Kafka 2011, p. 35) whereas interventions in form of prioritization or price discrimination are explicitly permitted, provided verifiable objective criteria do exist, that guarantee “testable objective criteria that do not hinder [or even block] an efficient competitor“ (Vogelsang 2007, p. 220).

All definitions of net neutrality, however, have in common that in principle a violation of neutrality does exist in the unequal treatment of content, specific applications or certain competitors (Grove et al. 2012, Hart 2011, Shell 2014) that contradicts the three basic principles of a neutral Internet – the *best-effort principle*, the *end-to-end principle* and the *first-in-first-out principle* (van Schewick 2012). According the best-effort principle, each data packet is transmitted in a content-blind manner without any gradation, prioritization or discrimination (Grove et al. 2012, Schlauri 2010). Therefore, data are exchanged on equal terms to the same speed, regardless of its origin (“a bit is a bit is a bit”, Faulhaber 2011, p. 18). On the other hand, however, neither a guarantee on accuracy, delay or loss can be provided nor a specific speed of the data transfer can be ensured (Cremer et al. 2000, van Schewick 2010). For this reason, any packet delays or losses – even just by chance – are possible, whereas each packet bears the same risk of being delayed or getting lost (Vogelsang 2007). Thus, the transfer of data occurs according to an end-to-end principle (Saltzer et al. 1984) that is characterized by shifting the intelligence to the endpoints of the network infrastructure (Felten 2006) – i.e. the unique role of the network itself is the undifferentiated forwarding of data (Lemley and Lessig 2001, Lessig

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<sup>8</sup> Such strict interpretations of net neutrality, however; do not correspond to reality since at times of heavy use, it would immediately come to congestion in the data transfer, that can only be prevented by providing excess capacity that is, in turn, very costly (Krämer et al. 2013).

2002). The main task of the network operators (carriers) and the Internet service providers (ISPs) as intermediaries or gateways (Ammori 2014) has previously been the fastest possible, non-discriminatory, i.e. neutral transmission of data over their proprietary network or in the supply of Internet connectivity for users. Moreover, in case of temporary capacity bottlenecks, the data transfer should be conducted according a first-in-first-out principle – i.e. those data packets that have been sent first should also be transmitted first (Herman and Kim 2014), whereas the speed of data transmission is solely determined by the actual available bandwidth.

From an economic perspective, net neutrality is constituted by the *no-discrimination-* and *zero-price rule*, while ISPs are regarded as intermediaries (and potential gatekeepers) between the providers of content, services or applications<sup>9</sup> on the one hand and the users on the other hand in a two-sided market for Internet access (Krämer and Wiewiorra 2012, Rochet and Tirole 2006, Schuett 2010). According to the no-discrimination rule, ISPs should not be allowed to execute certain (technical) measures for network management within the last-mile access network to users (Cheng et al. 2011, Easley et al. 2016). In addition, vertically integrated ISPs may not discriminate data from CPs that are potential competitors in the generation and distribution of content and services (so called vertical foreclosure; cf. Singer 2007). Especially the emergence of new technological procedures, like inter alia the so called “*deep packet inspection*” – *DPI*, that enable a content-related analysis of the transferred data packets, make it easier for ISPs to actively and purposefully intervene the data transfer (Grove and Agic 2012, Mochalski and Schulze 2009, Mueller 2011, Mueller and Asghari 2012, Picot et al. 2012). As a consequence, such interventions are assumed to be discriminatory actions and potential threats for the openness of networks if ISPs *block, throttle, cap* or *manipulate* (at least parts) of the data streams (cf. Holznagel et al. 2010, p. 3). The zero-price rule, instead, follows the logic that CPs are only charged once for getting access to the Internet (i.e. by ISPs offering access to the backbone), and not again for a (prioritized) delivery of data to end users at every terminating ISP (Hemphill 2008, Kourandi et al. 2015, Lee and Wu 2009).

As already mentioned, the evolution from former analog towards *horizontally convergent digital infrastructures* has also far-reaching consequences regarding the debate on net neutrality and its prevailing principles. Most importantly, the emergence of novel services, based on convergent digital infrastructures also pose complex functional requirements (Vogelsang 2013) that exceed

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<sup>9</sup> In this study, we summarize this group of economic actors to “content providers” (CPs).

pure capacity needs – e.g. near to real-time-requirements (Statovci-Halimi and Franzl 2013) in the field of smart traffic planning or for the control of machines and vehicles within the mobility domain.

At the same time, new requirements regarding the quality, reliability, and efficiency of the data transfer are imposed (Statovci-Halimi and Franzl 2013). In other words, services on the basis of converging infrastructures often require reliable access to (and exchange of) data from heterogeneous sources in dedicated quality while, at the same time, specific privacy and security requirements have to be fulfilled (e.g. in case of the fusion of data from the mobility- and health care sector for an efficient emergency transport in situations of heavy traffic).

Last, the emergence or the rising importance of data- and service platforms that act as orchestrators and potential gatekeepers (e.g. data- or application service providers that facilitate individual, cross-domain solutions and, thus, have a large impact on the flow of data and information) give rise to new questions regarding the aspect of “neutrality”, while in a classic interpretation of net neutrality just Internet service providers are regarded as critical gatekeeper in the exchange of data and for the access to content and services (Krämer et al. 2013).

Currently, no studies exist that explicitly deal with net neutrality in the context of such *convergent digital infrastructures*. The scientific discourse in literature, however, already indicates that the current debate on net neutrality, which is primarily related to the network layer of the Internet ecosystem with ISPs as critical gatekeepers at the so called last-mile network to the users, should be extended to focus on the entire value creation of the Internet. The reason behind claim is the fact that new competitive dynamics and novel forms of gatekeeping can emerge downstream as well as upstream the value creation level of Internet access (Krämer et al. 2013, Renda 2010).

First, the so-called *device neutrality* (cf. Hahn et al. 2007, Krämer et al. 2013) purports that neither the producers of (terminal) equipment (e.g. smartphones) nor the developers of the compatible software or operating system (e.g. *operating system neutrality*; *Apple - iOS* or *Google - Android*) should have influence on what content or which services can be accessed by the devices (e.g. *Apple* does not support Flash on its *iOS* devices). Moreover, also network operators should not have any influence on the variety of services and functions running on the devices (e.g. the blocking of *Skype* on mobile devices by ISPs). This concept was primarily designed as part of the debate on net neutrality in the mobile market.

Second, the concept *service- or platform neutrality* considers the prevailing shift of market power from ISPs towards data-, content-, and service providers and platforms (e.g. *Google*) that could be exploited by these market players for their own benefits in an opportunistic way (Sahel 2011, Shin 2014). This is the case, for example, if an operator of a search engine deliberately discards content of certain competitors from the overall search results (i.e. *search neutrality*, cf. Grimmelmann 2010, Jarosch 2011, Krämer et al. 2013, Odlyzko 2009).

Third, by conceptualizing their research program on *data neutrality*, Easley et al. (2016) broaden the classic view on net neutrality to the effect that they extend the field of analysis to other gatekeepers than ISPs between the content- (i.e. CPs) and the consumer side (i.e. users) in the Internet market. Hereby, they refer to the already mentioned *search- and operating system neutrality*, but also to a so called *browser neutrality* as internet browser – including the associated plug-ins and software extensions – can directly have an influence on what content is displayed (cf. Easley et al. 2016, p. 21).

In contrast to the approaches mentioned before, we abandon the exclusive view on the (narrow) Internet market and its potential gatekeepers and broaden our perspective by referring to potentially critical gatekeepers that could play a crucial role for the roll out of *converged digital infrastructures* and the novel, cross-domain services and applications based upon.

Thereby, we aim at a more holistic approach on “neutrality”, by identifying distinctive extension to the classic view net neutrality that can be derived from a *technology-, data-, or service-specific* perspectives within three distinct levels of analysis that structure the mobility sector as primary field of investigation (see chapter 3).

### **3. Methodology**

As a consequence of its novelty and high practical relevance, the analysis of *convergent digital infrastructures* in the context of (net-)neutrality is methodically carried out in form of a case study-based approach. According to Robert K. Yin (2003, p. 13) a case study is defined as “an empirical inquiry that investigates a contemporary phenomenon (,the case’) in depth and within its real-world context especially when the boundaries between phenomenon and context may not be clearly evident“.<sup>10</sup> Thus, this study design is focused on the collection of rich information

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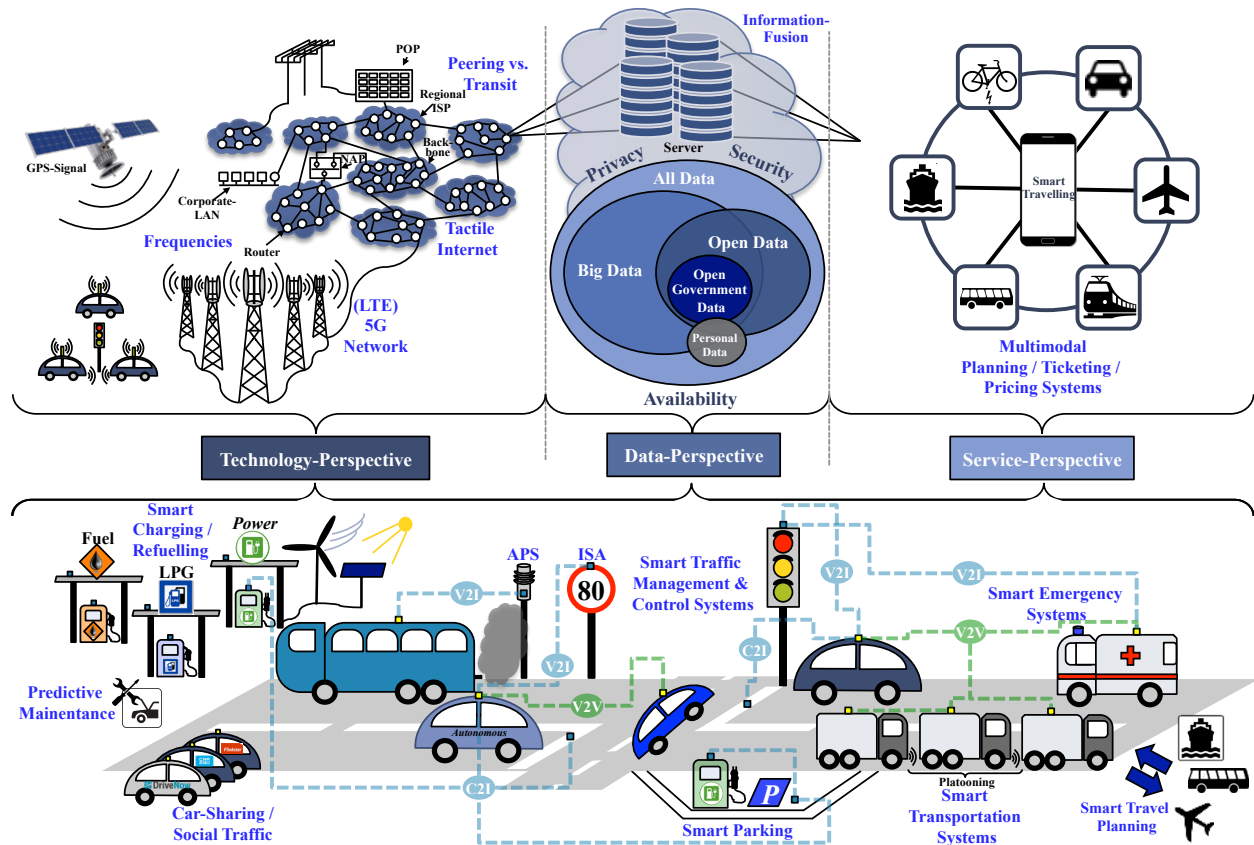
<sup>10</sup> For an alternative definition of case studies, see e.g. Eisenhardt and Graebner (2007, p. 25): “Case studies are rich, empirical descriptions of particular instances of a phenomenon that are typically based on a variety of data sources”.



(Eisenhardt and Graebner 2007), facilitated by the detection and analysis of typical practical problems (Yin 1981). Thereby, it is regarded as a starting point and foundation of subsequent theories (Eisenhardt 1989). The case study approach allows a purposeful and comprehensive reflection of the reality, taking into account the complex interaction of various determinants and impact-factors (Göbel 2009, Yin 2003). Because of the inherent shortage of theory that comes along with the analysis of *convergent digital infrastructures* in the context of neutrality, we follow a descriptive and exploratory approach. On the one hand, (new) requirements of the concept of net neutrality will be described, while, on the other hand, an investigation is necessary, whether it requires a new or extended understanding of “neutrality” in the context of a service ecosystem that is built on digital infrastructures (cf. Eisenhardt 1989, Yin 2003).

Since the complex interrelationships and interdependencies within *convergent digital infrastructures* can not be readily analyzed in a holistic manner, this study focuses on the mobility domain as primarily field of analysis and generalizes the derived insights for other areas or domains (i.e. it represents a so-called instrumental case study, cf. Göbel 2009).

For the analysis of digital mobility infrastructures in the context of (net-)neutrality, a novel approach has been developed that, on the one side, meets the requirements of a clear structure of the object of investigation (Yin 1981) and, on the other side, implies a comprehensive, overarching understanding of “neutrality” that exceeds the non-discriminatory transport of data over the proprietary network of ISPs. In other words, we analyze the digital infrastructures in the context of neutrality aspects from a *technology-, data- and service-specific* perspective within a so called smart mobility ecosystem. For a schematic representation of the field of analysis with the different perspectives, see the following Figure 3.

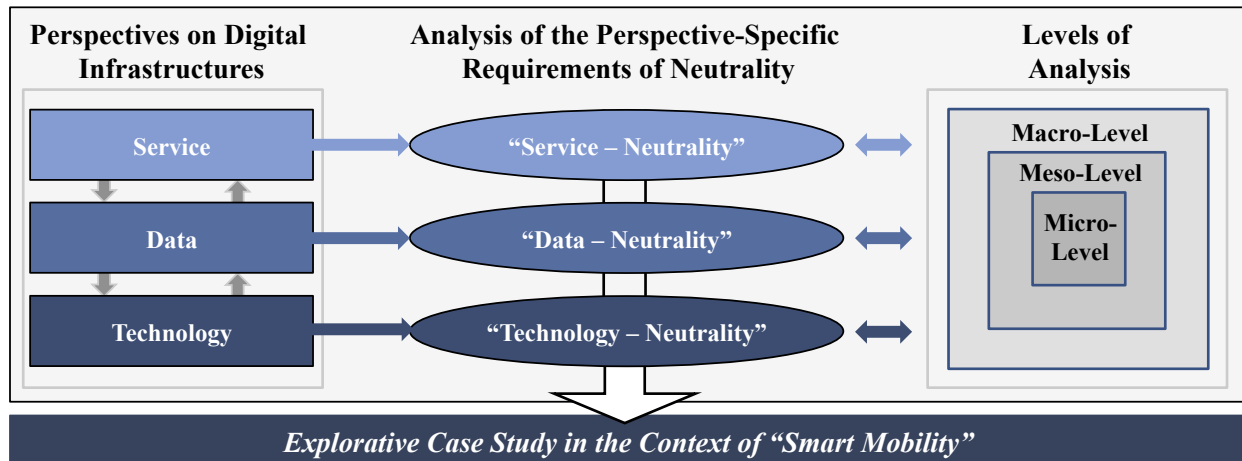


**Figure 3: Perspectives on Convergent Digital Infrastructures in the Smart Mobility Ecosystem (Own Illustration).**

Thereby, the scope of the discussion in the *technology-perspective* exceeds the discussion within the concept of device neutrality (Hahn et al. 2007), as our analysis also refers to differentiations between several forms of sensor- or access networks, specific transmission standards, and the integration of various ICT-modules (i.e. ICT-hardware in general).

The *data-perspective* discusses the principally non-discriminatory, ubiquitous data availability from heterogeneous sources, with special focus on the distinctive requirements on quality, (near to) real-time usability and privacy- or security-relevant criteria.

Finally, the changing relationships and interdependencies due to the entry of new data- and service platforms, whose value chains can be modularly configured and assembled to network-like business models (acatech 2015b) are discussed in the *service-perspective*. For a schematic illustration of the procedure, the perspectives and the specific levels of our analysis as defined in the paragraph below, see Figure 4.



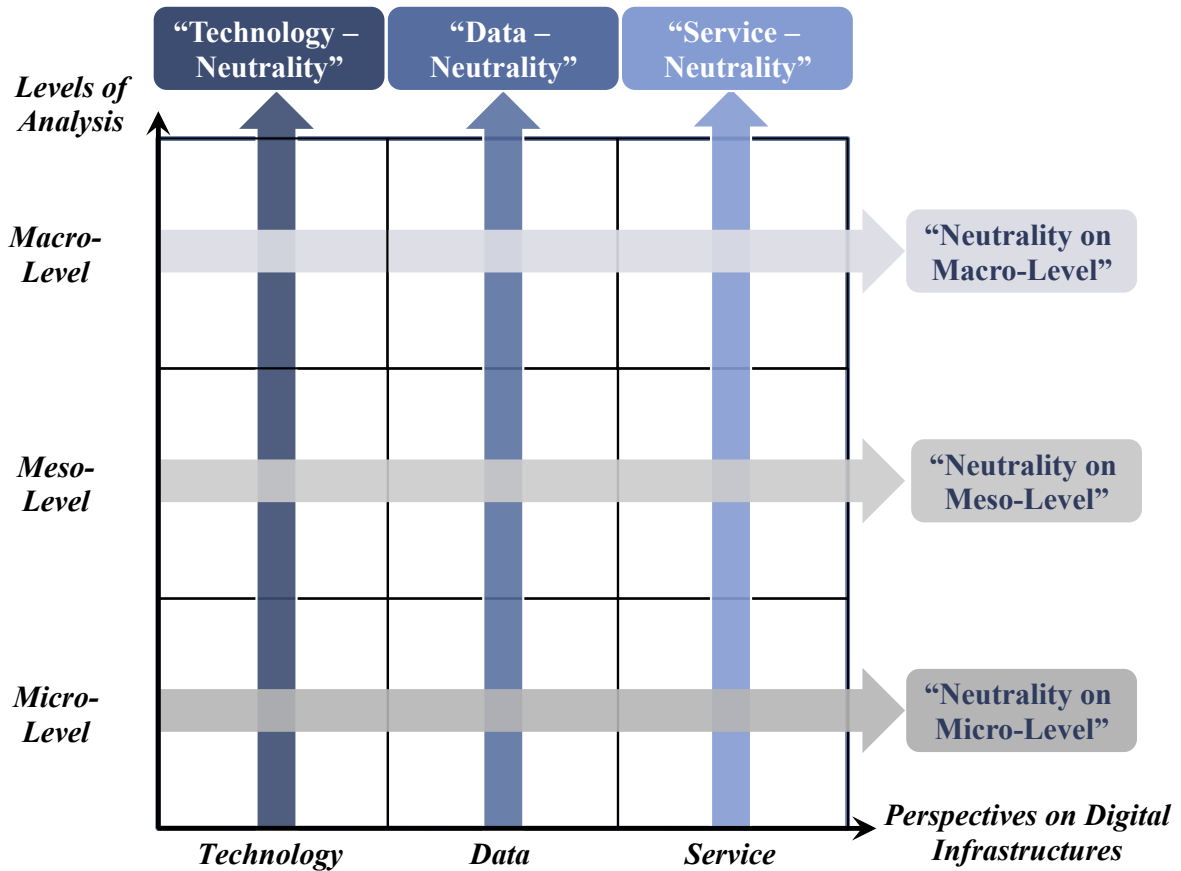
**Figure 4: Procedure, Perspectives, and Levels for analyzing Digital Infrastructures in the Context of Neutrality (Own Illustration).**

To account for the scope of the evolutionary steps towards *horizontally convergent digital infrastructures*, cf. chapter 2.1), we divide the mobility sector as primarily field of investigation in this case study into a a) *micro-*, b) *meso-*, and c) *macro-level* and analyze this levels – as mentioned before – from a *service-, data-, and technology-perspective*.

The *micro-level* focuses on the single means of transportation – in our case primarily the connected, sensor- and ICT-embedded electric car, its digitization and interaction with the specific digitized infrastructure components like, for example, sensor-added traffic lights.

The *meso-level* refers to the integration and interconnection of various modes of transportation in *vertically convergent mobility infrastructures* (cf. chapter 2.1).

Last, the *macro-level* examines the horizontal convergence of digital mobility infrastructures and its services with digital infrastructures of other domains. This constitutes the third evolutionary step: the *horizontally convergent digital infrastructures*. In combination with the three different perspectives to examine the digital infrastructures (i.e. the *technology-, data-, and service-perspective*), the different levels of analysis offer an novel view on the topics of (net-)neutrality as depicted in Figure 5).



**Figure 5: Structuring the Field of Investigation: Levels of Analysis & Perspectives on Digital Infrastructures (Own Illustration).**

The methodological process of the qualitative case study (Lamnek 2010) is primarily guided by the procedure model of Eisenhardt (1989, p. 533), starting in the preparation stage with an extensive literature review of scientific articles and studies focusing on net neutrality and *(convergent) digital infrastructures* services in order frame the research question. Already here, relevant and evident constructs (in this case, for instance, statements regarding device- and service-/platform neutrality) were identified and taken into account for further analysis. Following this stage, a broad analysis of future-oriented studies (primarily in the context of the mobility sector) has been conducted in order to envision the future mobility infrastructures and its requirements, which is the main object of investigation in order to provide the basis for the analysis of neutrality on the respective levels (*micro-, meso-, and macro-level*). In addition, a triangulation of methods (Chmielewicz 1994) – esp. by reflecting our findings from desk

research with insights, derived from statements of experts, previously collected in interviews<sup>11</sup> – is used in this study in order to gain substantial knowledge and, moreover, to validate the conclusions and hypotheses drawn in this analysis. In the next step, the hypotheses on neutrality drawn from this analysis of *convergent digital mobility infrastructures* can be checked for applicability in other domains (e.g. the energy-, education-, or administration sector).

#### 4. Analysis

As outlined in the methodology-section, we divide *convergent digital infrastructures* in the context of mobility into three distinctive levels of analysis – the *micro-*, the *meso-*, and the *macro-level* – that are graphically illustrated in Figure 6.

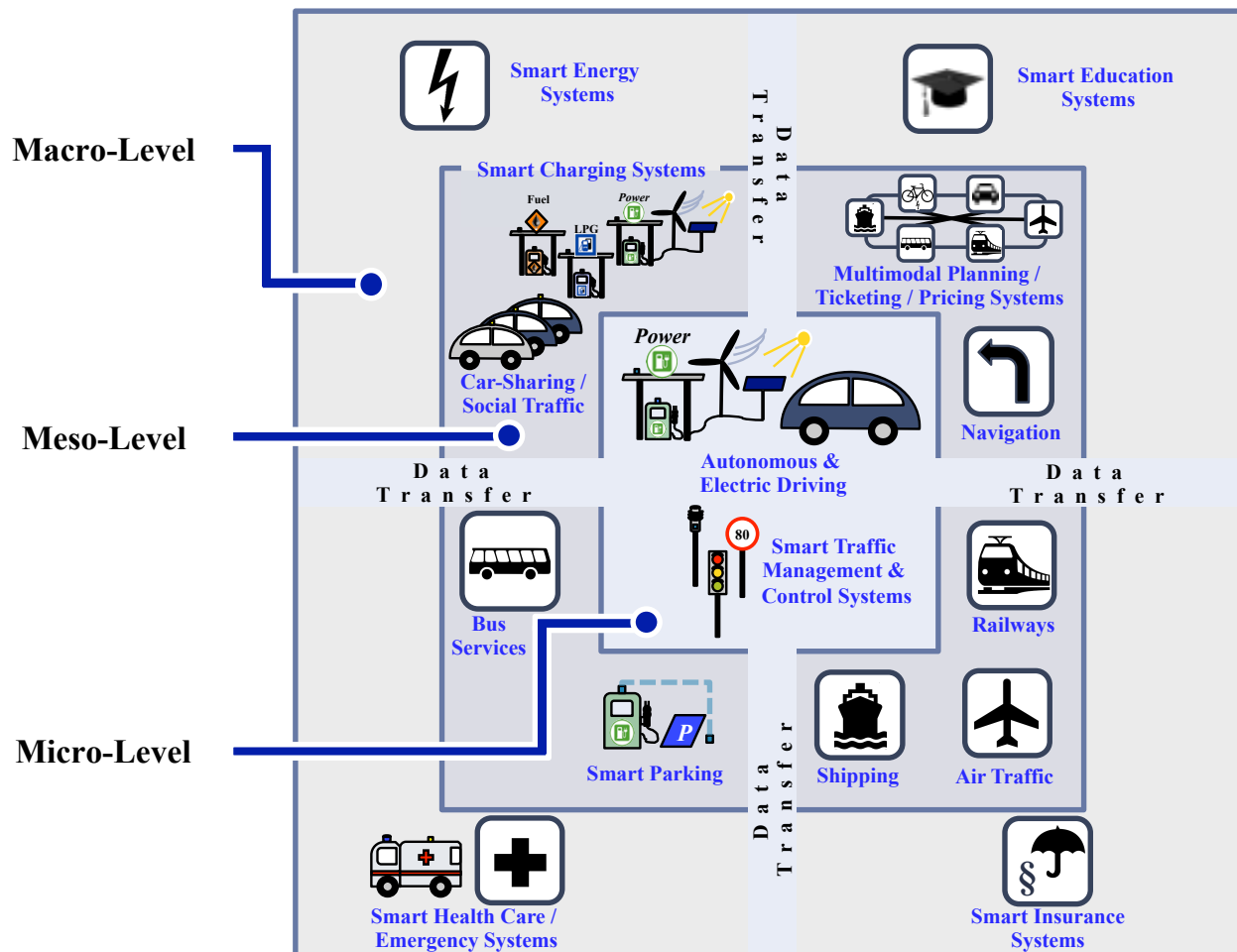


Figure 6: Micro-, Meso-, and Macro-Level of Analysis (Own Illustration).

<sup>11</sup> The authors had the chance to collect substantial sector-related knowledge and to gain insights to future developments in the field of mobility by a large number of expert interviews and discussions, conducted for three research projects that were financed by the German Federal Ministry for Economic Affairs and Energy (cf. Bernard et al. 2011, Krcmar et al. 2016, Picot et al. 2014).

The analysis of each of these levels begins with a brief description of the main characteristics and potentials. In a second step, the key aspects and prerequisites from a *technology-*, *data-*, and *service-perspective* are discussed in the context of (net-)neutrality.

#### **4.1. Micro-Level**

The increasing usage of digital technologies and the pervasive penetration of ICT in everyday life (e.g. private or professional usage of laptops, smartphones, or tablets) lead to a higher general ICT affinity and, thus, to changing demands of users (cf. Krcmar et al. 2016, Münchner Kreis 2017, Picot et al. 2016, Picot and Neuburger 2015). In the context of the *micro-level*, that primarily focuses the (connected) electric car, its digitization and interaction with other vehicles and the surrounding digitized traffic infrastructure, this trend is of high relevance. Customers of cars (esp. the young, tech-savvy people) increasingly ask for an integration of digital technologies like intuitive touch-based control interfaces, components allowing seamless connectivity, entertainment systems, and the provision of various functions via apps in their vehicles, whereby a demand pull for digital functions is observable (Picot et al. 2016). Moreover, the technological progress facilitates the implementation of ICT not only in vehicles but also in previous analog traffic infrastructures, whereby this process of digitization as technology push is the precondition for the communication among vehicles (i.e. vehicle-to-vehicle – V2V) or between vehicles and the infrastructure (i.e. vehicle-to-Infrastructure – V2I) and the functions or services based upon, that can generally be classified into three complexes of innovations (cf. Rammler 2014): a) *orientation innovations*, b) *acceleration innovations*, and c) *interconnection innovations*. The orientation innovations cover sophisticated navigation solutions for positioning and the identification of the most efficient route to the place of destination while processing data from various sources like GPS-satellites, sensors integrated into the transport infrastructure and control systems (e.g. roadways, traffic lights, etc.), or from the interconnection of vehicles via the Internet and corresponding mobile communication networks (e.g. near field communication [NFC], 5G-, and LTE-networks). The acceleration innovations, instead, promote the shift from fossil to sustainable driving concepts like electric mobility, powered by renewable sources of energy to reduce the overall greenhouse gas emission<sup>12</sup> (Canzler and Knie 2016). Finally, the interconnection innovations reflect the coupling of traffic systems with ICT-networks and enable

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<sup>12</sup> To limit the temperature rise due to climate change below 2 °C, by 2050, the EU aims at reducing the emissions by 80-95% compared to 1990 (European Commission 2011).

the exchange of data via V2V or V2I and, therefore, constitute the precondition for driverless or autonomous mobility solutions.<sup>13</sup>

Such innovations, in which product-related and systemic infrastructure innovations are combined (Rammler 2014), however, come along with specific requirements that refer to the basically non-discriminatory transmission of data within and across communication networks, to the access to data from heterogeneous sources, and to the granted access to various services and applications. In the following section, these requirements will be analyzed in the context of neutrality from a *technology-, data- and service-perspective*.

### ***Technology-Perspective on the Micro Level***

The integration of digital interfaces or functions in vehicles and the realization of the various innovations for navigation (e.g. smart navigation solutions), acceleration (e.g. electric mobility), and for interconnection (e.g. autonomous driving) entails several, in part complex technical requirements. While the engine performance, clearance, or the workmanship of the interior have been important quality features and, thus, represented elementary purchase criteria for potential buyers of cars in the past, the equipment of the vehicle with modern ICT that enables the interconnection with the environment, interactive assistance functions like lane departure warning systems or traffic jam warnings (IT Gipfel 2014), and infotainment applications such as news streaming and the processing of data from dedicated mapping companies (Johanning and Mildner 2015) provide new unique selling propositions (USPs) for customers. Accordingly, cars are evolving towards “the ultimate mobile devices” (Bradshaw 2015) and are often regarded as “smartphones on wheels” (The Economist 2014), that require a performing car IT-system that goes beyond an integration of electronic or electrical components that are needed for the processing of only internal, car-specific sensor data. Rather, the embedding of sophisticated ICT-modules is needed that guarantee the communication to other cars (i.e. V2V), to the traffic infrastructure (i.e. V2I) and to all other addressees (i.e. V2X) via reliable communication standards. Therefore, similar to digital devices such as tablets or smartphones, such cars as integrated systems can be regarded as extensions to increasingly diffused digital infrastructures. In the emerging “connected cars”, besides audio, telephone, and navigation modules, the IT-architecture enables mobile online functions, whereby the head unit (HU) or on board unit

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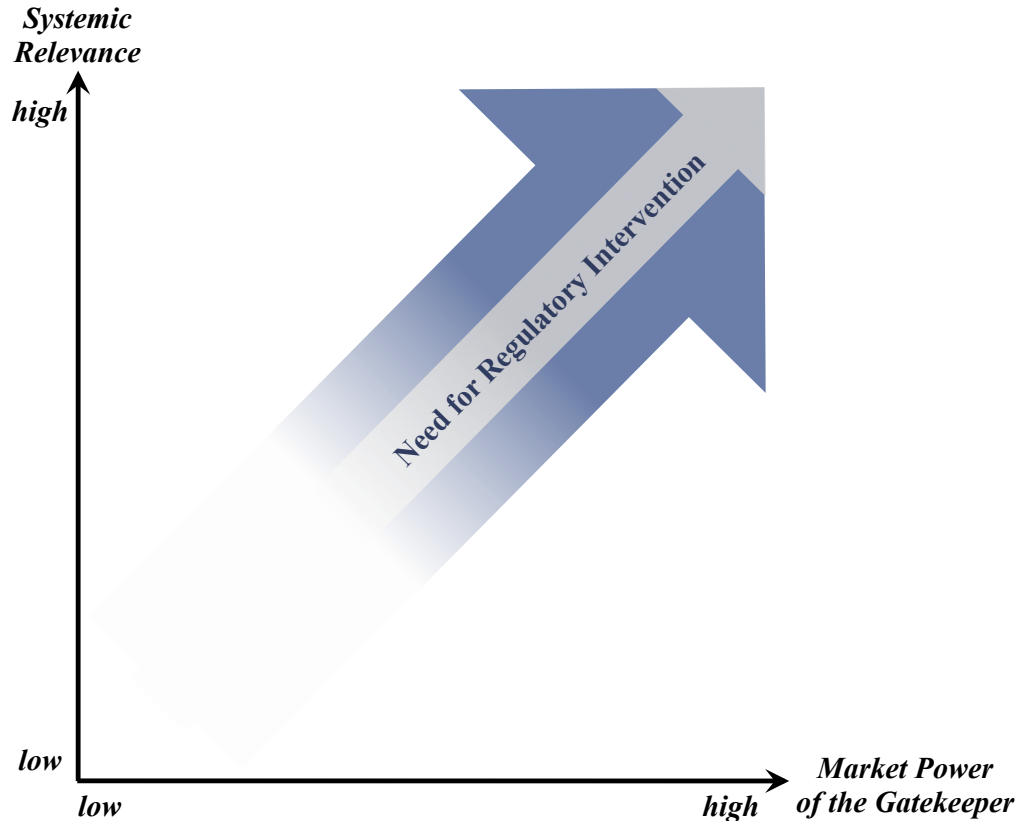
<sup>13</sup> Moreover, this comprehensive interconnection is a substantial precondition for the development of intermodal mobility services as analyzed in chapter 4.2.

(OBU) with an human-machine interface (HMI, e.g. a touch screen) represents the central control unit for users, where all functions, based on data from inside (e.g. sensor data) via data buses (Wedeniowski 2015) and from outside the car (via NFC or mobile communication networks) are processed and displayed. The connectivity control unit (CCU) or the online connectivity unit (OCU) with an integrated SIM card ensures a permanent connection to the Internet (cf. Johanning and Mildner 2015). Such car-IT functions in connected cars include, inter alia, vehicle-related functions, based on data generated within the car (e.g. regarding the vehicle condition or battery-level, often also accessible via remote diagnostics) and infotainment functions that require a permanent connection to the Internet – e.g. information on real-time traffic, social networking, news streaming, and weather- or location dependent information (Johanning and Mildner 2015).

The debate on *device neutrality* addresses the question, whether device manufacturers or owners of software- or operation systems should have control over the services and applications consumed on mobile phones (cf. chapter 2.2 and Hahn et al. 2007, Krämer et al. 2013). Transferred to the context of (vertically and horizontally) convergent digital infrastructures and their intelligent interconnection, an extension to the concept of “device neutrality” to an general *(IT-)system neutrality* seems to be appropriate. Thereby, concerning the (connected) cars (and particularly their IT- or ICT-based hardware) in smart mobility networks, the question comes up whether car companies as original equipment manufacturers (OEMs), the producers of the car-IT system components (if not designed and manufactured by OEMs) or the owners of the installed infotainment- or operating systems (e.g. *Apple: CarPlay; Google: Android Auto*) as potential gatekeepers between the users of such systems on the one side and the developers or producers on the other side should have the power to predetermine, which functions, services or applications are compatible with their (proprietary) system.

In order to decide whether or to what extent a comprehensive *IT-system neutrality* should be enforced by regulatory interventions, it seems to be an appropriate way to look not only to the market power of the potential gatekeeper(s). Rather, it is also necessary to assess the (systemic) importance of the application or service at stake (cf. Easley et al. 2016). The higher the systemic relevance of a service and the higher the market power of a (potential) gatekeeper, the more a regulatory intervention to safeguard neutrality in a specific field of application seems to be appropriate (see Figure 7).





**Figure 7: Dimensions for Assessing the Need for Regulatory Intervention**  
 (Own Illustration, based on Easley et al. 2016, p. 19).

In order to assess the systemic relevance – i.e. in our context: the realization of autonomous driving systems and the provisioning of specific services or applications for functioning intermodal travelling solutions, based on *convergent digital mobility infrastructures* – a differentiation between entertainment-, functional- and safety-related applications running on the (car-IT) systems seems to be necessary. For entertainment services (e.g. gaming, video- or audio streaming), due to the rather small systemic relevance for the implementation of autonomous or connected mobility solutions, the developers or producers of IT-systems may decide on their own whether they open their system to third party companies or software developers or not and, therefore, can act as gatekeepers for this specific type of service. Moreover, such foreclosure of potential competitors could also offer space for differentiation against potential competitors and may create incentives for further investments and improvements of their proprietary system. On the other side, excluding potential suppliers of complementary infotainment services and

applications implies the risk, that such “closed” systems become less attractive for potential users (cf. Easley et al. 2016)

If a service, however, can be categorized as functional service – related to autonomous driving or to the basic mobility function required for planning, operating, pricing and even billing (or for the integration in intermodal mobility services, cf. chapter 4.2), it seems to be favorably for functioning intermodal smart mobility solutions to open the system to third party actors that offer complementary functions, thus, enforcing a *IT-system neutrality*. The same applies for safety-related services and applications (e.g. for traffic- or accident warning) that should be accessible for users of various (proprietary car-)IT systems in order to enable high-performing and secure solutions for smart mobility.

The realization of autonomous driving, as a currently prominent and widely discussed aspect in the context of mobility, requires – besides the combination and automation of various assistance functions such as line-keeping systems, automatic parking systems, or an adaptive cruise control (Johanning and Mildner 2015) – the comprehensive integration and processing of both internal data from sensors embedded in the vehicle and from outside the car via V2V- respectively V2I-communication (based on a derivative of the WiFi-standard) or a reliable and stable mobile communication technology (LTE, 5G). Therefore, in addition to a general accessibility, the network infrastructures have to fulfill specific requirements, particularly relating to the range and data rate respectively bandwidth, (near to) real-time capability, reliability and latency, in order to facilitate an adequate processing of data from various sources on time. The range of V2V- and V2I-connections is limited to several hundred meters up to one kilometer (Reder 2014) to facilitate a low-latency ad-hoc connection to other vehicles and sensor-added infrastructure components like traffic lights or traffic control- and traffic information systems (Johanning and Mildner 2015). For longer distances, however, the connection to mobile communication networks (e.g. LTE or 5G), radio communication, or satellite is required that are provided as hybrid network (IT Gipfel 2014). Especially in the context of autonomous driving, sending and receiving functional- or safety-critical data between different components of the network in (near to) real-time is essential, supporting the requirement of a general generally ensured *transmission neutrality* – i.e. the access to all relevant types of transmission networks has to be guaranteed for every single car, independent from the type or manufacturer respectively its IT- or ICT-components.

Moreover, in order to realize intelligent mobility solutions in a systemic context, a general compatibility in the connectivity of vehicles from various OEMs and between the vehicles and infrastructure components has to be guaranteed in a non-discriminatory way – i.e. by setting a generally accepted standard in order to avoid any restrictions in operability as it is has been the case between the different V2I-, V2V, or V2X-concepts developed in the US or in Europe (cf. Reder 2014). This gives rise to the demand for a generally accepted *interconnection neutrality*.

### ***Data-Perspective on the Micro-Level***

The realization of (electric-)autonomous cars decisively depends on the access to several sources of data and to (mobile) communication networks (e.g. via WiFi-based V2V/V2I interconnection or LTE/5G networks). Therefore, propositions that the debate on net neutrality is not concerned with driverless cars because the gathering and processing of the required data is not primarily based on Internet access (Beckedahl 2015a, b, Golem 2015) seems to fall short. As mobile Internet connection is a necessary precondition for the distribution of information regarding road conditions, remote diagnostics, location-related information, alternative routing, emergency communication or extended navigation services (Reder 2014), the neutrality aspect regarding internet access, data and services may not be ignored. Furthermore, some functions depend on a distinct, clearly defined transmission performance. For example, safety-critical services such as wrong-way driver warnings require underlying data in a guaranteed, near to real-time transmission with short response times, low latency and negligible jittering (IT Gipfel 2014). By demanding a dedicated quality and, in consequence, a prioritized data transmission (i.e. quality of service – *QoS*), the basic principles of a neutral Internet (i.e. the best-effort principle, the end-to-end principle, and the first-in-first-out principle” cf. chapter 2.2) are generally violated. This deviation from (net-)neutrality, however, appears to be reasonable as long as safety-critical data (e.g. referring to accident reporting) are prioritized over, for instance, data just transferred for entertainment services in case of capacity constraints. This unequal treatment of different data, however, has to be generally executed in an application agnostic manner<sup>14</sup> (van Schewick 2010, 2015), so that no single applications- or service provider is disproportionately adversely affected by such methods that, in consequence, otherwise could lead to competitive distortions.

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<sup>14</sup> Application agnosticism means that even there is an ability to differentiate among applications on the network and, therefore, to differentiate the referring data packets, no distinctions among these data packets is made that could lead to an discrimination of single application providers (van Schewick 2015).

Last, in order to stimulate innovations and new business models in the field of mobility and related services, a generally open access to anonymized data, generated by vehicles (i.e. “devices”) and by the traffic infrastructure (e.g. sensor-added traffic lights), leading to a *neutral access to infrastructure (IS)- & device data* seems to be appropriate. However, exceptions need to be possible as, for instance, the myriads of telemetry or sensor data a manufacturer of connected cars collects in order to develop or improve a completely driverless vehicle may remain proprietary.<sup>15</sup> A disclosure of such data sets would implicate a competitive disadvantage for the manufacturer that may result in decreasing incentives for future investments.

### ***Service-Perspective on the Micro-Level***

As depicted above, access to infrastructure and device data is a necessary precondition to develop data-based services and applications as already illustrated for the mobility sector. Similar to our argumentation within the *technology-perspective*, there could be a platform- or service operator (as potential gatekeeper, cf. chapter 4.2) whose market power allows him to block services or applications from potential competitors in an opportunistic way – e.g. due to the control of the necessary access to data or by hindering the competitors from running their services on the (car-IT) devices. Therefore, one can assume that a *neutrality of services based on infrastructure- and device-data* would safeguard a vital competition between various service providers, resulting in a high-level of variety and innovation.

Whether this requirement should be fulfilled through ex ante regulation or by traditional ex post anti-trust policy measures should be subject to political decision-making. Currently, the latter strategy seems so prevail which improves the incentive for innovative platform development.

## **4.2. Meso-Level**

On the *meso-level* we broaden the focus of the analysis from the single connected or autonomous vehicle to a smart mobility ecosystem that reflects the integration of various modes of transportation with their (initially) dedicated infrastructures to a vertically, *domain-specific convergent digital infrastructure* – i.e. we shift the analysis from a coexistence to a convergence of mobility options (Festag et al. 2016). Such emerging smart mobility ecosystems, built on the logic of *vertically convergent digital infrastructures* (cf. chapter 2.1) that are realized through an

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<sup>15</sup> Here, however, a weighing up of interests is still necessary. Smaller, less well-financed OEMs won't be able to develop autonomous driving systems by their own and the market could be reserved for few very large companies. This, in turn, could result in negative consequences for the overall development and security of autonomous systems.

ICT-driven convergence of the infrastructures within a single domain (in our case: the mobility sector). It enables intermodal travelling options based on the ICT-driven interconnection of a multitude of different means of transport, including the (physical) infrastructure components and, moreover, offering standardized cross-functional services, such as identification and billing methods. That means, the single connected vehicle (or any other means of transport) is no longer regarded as an autarkic, independent device that acts as “autonomous radical” (Canzler and Knie 2016, p. 75). Instead, it requires an ICT-based integration in a super-ordinated intermodal (meta-)system that enables end-to-end traffic chains, built on a seamless transition between different mobility options (Rammler 2014, Wedeniwski 2015) like, for example, (autonomous) cars, the short-range transit, rail-, air-, and shipping traffic.<sup>16</sup> In this vein, owning a car becomes more and more obsolete to satisfy the individual mobility needs. Instead, its transport function and interconnectedness to various means of transport is more and more important (Krcmar et al. 2016). The potentials of smart mobility solutions, based on a vertical convergence of the digital infrastructure of various modes of transportation due to embedded and interactive ICT-components are manifold. They include, inter alia, a higher degree of safety and capacity utilization of the existing traffic infrastructure (IT Gipfel 2014). In order to realize such integrated mobility solutions, mobility service providers act as orchestrators of the different modes of transportation (and the referring particular [digital] infrastructures) with focus on the connection of heterogeneous distributed traffic systems in order to create smart, customizable solutions for the passengers (Wedeniwski 2015).

### ***Technology-Perspective on the Meso-Level***

Managing or operating smart mobility services, based on *vertically convergent digital mobility infrastructures*, requires a digital mapping of the various modes of transportation with information on position, availability, accessibility and price that can be readily requested and visualized on a central digital mobility platform (Canzler and Knie 2016). Therefore, a coexistence of three different worlds or realities does emerge: next to the real, physical world and the world of digital data, there is a complex world in between (Rammler 2014). As part of the dialectic relationship between the physical, analog presence and the digital appearance, a

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<sup>16</sup> Hereby, the relevance of such comprehensive mobility solutions is indisputable, as particularly for younger people a shift in preferences is visible: physical cars are often no more regarded as status symbols and, therefore, their function – i.e. the ubiquitous and individualized mobility – is increasingly demanded without any ownership aspirations (c.f. Krcmar et al. 2016, Münchner Kreis 2017, Picot et al. 2016).

tendency to dematerialization or virtualization is observable. As a result, the physical (e.g. color) or status-related (e.g. brand) properties of devices such as cars are becoming less important, while the focus is rather placed on their specific functions – e.g. the transport capacity, ubiquitous availability and a reservation option via virtual mobility platforms – and the ability for an integration in intermodal mobility solutions (Canzler and Knie 2016). Only by virtualizing the various means of transport and their software defined integration enables system-wide planning and an efficient management of intermodal mobility solutions.

The underlying infrastructures of smart mobility solutions have to be connected via various communication and transmission networks (e.g. LTE or 5G, radio communication, satellite), with guaranteed data access from the different relevant networks, requiring a general *transmission neutrality* as discussed in the *micro-level* of analysis (cf. chapter 4.1).

In addition to a general connectivity between cars of various OEMs, also the interconnection of infrastructure components has to be guaranteed in a non-discriminatory way as argued on the *micro-level*. In addition, in the context of the *meso-level*, also the non-discriminatory integration of several modes of transportation (e.g. cars, railways, etc.) in a holistic mobility system is essential. Therefore, the demand for setting a generally accepted standard in order to avoid any restrictions in interoperability within convergent smart mobility solutions requires a *domain-specific interconnection neutrality* on the *meso-level*.

### ***Data-Perspective on the Meso-Level***

Smart mobility solutions require the access, transmission, collection, processing and analysis of data from heterogeneous sources such as the various transportations means, its underlying (digital) infrastructures and users. At the infrastructure level, data indicating the current traffic situation or capacity utilization can be used, for instance, to build up an situation-specific intermodal mobility service that leaves out any congested transportation options. At the vehicle level, in contrast, access to location-based data, to indicators regarding the available shipping volume, or to telemetry data are necessary to develop, inter alia, smart traffic control applications, the real-time allocation of passengers or cargo depending on the time-, location- and capacity related availability of different vehicles or other means of transport, and the conceptualization and implementation of new services, based on remote maintenance (IT Gipfel 2015). Moreover, user- or passenger-based data can be used for customizing smart mobility solutions according to individual preferences and user behavior.

The feasibility of such potentials, however, decisively depends on the open accessibility of the underlying data while, simultaneously, an adequate level of data privacy or safety and anonymity has to be guaranteed. Therefore, a discrimination free, i.e. *neutral access to heterogeneous domain data* is necessary, as long as such data-sets are required to realize smart mobility solutions in a systemic, comprehensive, that means intermodal way. In this vein, a cloud-based, open-source access of public data (i.e. mobility- and geo-data) drives the development of a variety of new applications or services by potential service providers. This may be not applicable, however, for cases in which the disclosure of data sets would result in a competitive disadvantage for a single actor, as this probably decrease the incentives for future investments. This is the case, for example, for the telemetry data collected by car manufacturers that are necessary for the development of autonomous vehicles.

Relating to the question whether all data within *vertically convergent digital infrastructures* – as in our case within the smart mobility domain – should be transmitted in a non-discriminatory way or whether a differentiation in guaranteed *QoS*-levels has to be preferred, a similar line of argumentation may apply as in the *data-perspective* on the *micro-level* of our analysis (cf. chapter 4.1). Consequently, allowing *QoS* and, therefore, deviate from the principle of (net-)neutrality, appears to be justifiable in an application agnostic manner (van Schewick 2015) as long as functional or safety-critical data (e.g. referring to accident reporting) is prioritized over data transferred just for entertainment services in case of capacity constraints.

### ***Service-Perspective on the Meso-Level***

In emerging smart mobility ecosystems, built on the logic of *vertically convergent digital infrastructures*, mobility service providers are expected to take on a central role in the implementation of intermodal transportation solutions. As orchestrators among various means of transport and its specific infrastructures, their competence primarily relates to the virtual interconnection of heterogeneous distributed traffic systems in order to create smart, customizable solutions for their passengers (Wedeniowski 2015). Based on the virtualization of functions from initially dedicated physical transportation infrastructures, the choice of potential users of smart mobility service referring to the best suiting means of transport is directly transferred from a physical layer to the digital platform, run by a mobility service provider (Canzler and Knie 2016). This means, for example, to plan, book, operate and price the most efficient configuration of a seamless traffic chain that enables a passenger or cargo transportation

solution, while considering individual preferences (e.g. in terms of travelling time, price and convenience), algorithms compare the specifications of the virtually represented and connected means of transportation. In this context, passengers can be metaphorically regarded as “small packets” for which, provided with an integrated booking-, planning-, and payment system by the mobility service provider, an appropriate way through the labyrinth of different transportation options is arranged (cf. Rammler 2014). Following the logic of roaming in the mobile communication sector<sup>17</sup> (cf. Canzler and Knie 2016) users of an integrated transportation service won’t be charged separately for the use of various intermodal transportation means, but only have to pay once per trip.<sup>18</sup>

While it remains a critical question, which private or public institutions will operate such smart mobility platforms<sup>19</sup>, such operators will become critical gatekeepers for the development of vertically convergent mobility solutions. As the market power of companies that provide, operate and define the standards and interfaces of a smart mobility platform (i.e. the “shaper” of the platform, cf. Franz 2003, p. 40, Picot et al. 2016, p. 98, Zerdick et al. 2000, p. 179ff.) is significantly high (e.g. due to a large installed base of users or because of prioritized/proprietary access to data, necessary to run the platform), they probably can exploit this position in an opportunistic way – e.g. by a discriminatory exclusion or blocking of other (complementary) mobility services providers or suppliers of various means of transport (i.e. the “adapter” of the platform, cf. Franz 2003, p. 40, Picot et al. 2016, p. 98, Zerdick et al. 2000, p. 179ff.) and/or by setting prices for participating in the platform, that are prohibitively high for providers of complementary mobility solutions. Thus, in a wide interpretation of the concept of (net-)neutrality in the economic context by Schuett (2010), this opportunistic behavior would transgress both the no-discrimination-rule and also the zero-price rule (see also chapter 2.2). Moreover, excluding potential suppliers of complementary services implies the risk, that such “closed” systems become less attractive for potential users (see chapter 4.1). Therefore, in order to guarantee a large variety of complementary providers of mobility solutions and to ensure the entry of new players in the smart mobility ecosystem, a *domain-platform neutrality* should be pursued.

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<sup>17</sup> Here, mobile phone users only have to pay the incurred charges to the contractual cell phone service provider and not to each foreign carrier whose network was used while travelling abroad,

<sup>18</sup> Due to the fact, that the complete booking and managing process of the single transportation means is centrally operated by the mobility service provider, the overall transaction costs are minimized.

<sup>19</sup> For platforms, there exist a large number of context-specific definitions. For an overview, cf. Schmid (2010).



### **4.3. Macro-Level**

Finally, the *macro-level* of our analysis focuses on cross-domain services in *horizontally convergent digital infrastructures*. Thereby, the analysis is not limited to the digital infrastructure *within* a domain, but rather envisions the convergence of different digital infrastructures *across* domains – e.g. the energy-, health care-, administration-, and education sector (BMW 2012). The highest level of convergence is also characterized by so called *meta-(infra-)Structures* (e.g. smart cities), based on a convergence of several *vertically convergent digital infrastructures*. A typical example for the horizontal convergence between the mobility- and energy sector and its underlying infrastructures is, inter alia, represented by autonomous electric cars that become a part of a smart electric storage network (Canzler and Knie 2016). Here, to increase the flexibility, to bridge a temporary shortage in energy, and to compensate fluctuations in frequencies, connected electric cars can automatically be assigned to act as a portable electric storages. Therefore, the vehicle becomes part of a micro smart grid. Another example of horizontal convergence can be found at the intersect of the mobility- and health care sectors as, for instance, an autonomous car, connected with medical institutions, could execute a sensor-based health check on the passengers and automatically transport a passenger in need of immediate medical treatment to a nearby hospital by choosing the most efficient route. In addition, autonomous cars offer also examples for the convergence of the convergence of the mobility and education sector, as passengers of autonomous cars can use the time of travelling, for instance, for learning or for participating in online courses, optimized for this purpose. Simultaneously, insurance companies are already now able to permanently process and analyze the driver-specific usage data, transferred by connected cars in order to adapt the insurance policy according the driving habits. This reflects to some extend a convergence between the mobility domain and the insurance industry.

#### ***Technology-Perspective on the Macro-Level***

Similar to our argumentation on the *meso-level*, the virtualization, i.e. the digital representation or mapping of the various functions from heterogeneous domains, is essential to facilitate cross-domain solutions. Hereby, the broad integration of cyber-physical systems as interface between the real, physical world on the one side and the virtual world on the other side is necessary. The specific functions of the various domains can virtually be combined and interconnected like single modules – i.e. the virtualization and configuration of the different domain-specific functions enables a cross-domain, systemic planning and efficient management of services,

based on *horizontally convergent digital infrastructures*. Again, communication networks can be regarded as the backbone for a cross-domain convergence. Therefore, besides the widespread integration of cyber-physical systems, an ubiquitous, non-discriminatory, reliable, resilient, and real-time capable access to communication networks has to be guaranteed in order to allow an vital exchange of data among different domains (cf. Picot et al. 2014). Therefore, similar to the *meso-level* of analysis, there is demand for a general *transmission neutrality*. Finally, also the non-discriminatory interconnection of several heterogeneous and previously separately planned and operated infrastructures of various domains is essential. It emphasizes the need for setting a generally accepted standard in order to avoid any restrictions in interoperability of cross-domain smart service solutions. This, in turn, requires a *cross-domain interconnection neutrality* on the *macro-level*

### ***Data-Perspective on the Macro-Level***

The heterogeneity of data sources in the context of the *macro-level*, that is characterized by cross-domain services and applications on the basis of *horizontally convergent digital infrastructures* is unequal higher and also results in a generally higher complexity compared to the analysis on the *meso-level*. The non-discriminatory access to data from heterogeneous, previously independent and separately operated domains is, however, essential to build on services that integrate various cross-domain functions. At the same time, an adequate level of data privacy, safety and anonymity has to be guaranteed – e.g. for the collection of sensitive personal data from the health care domain. Overall, however, a discrimination-free, i.e. *neutral access to heterogeneous cross-domain data* is advisable.

Following a similar line of argumentation as in the *data-perspective* of the *meso-level* of our analysis, a foreclosure of data sets, however, is reasonable as long as the data are not required in a systemic sense, i.e. for the general functioning of a cross-domain service platform (cf. the following *service-perspective* in the *macro-level*). Therefore, as already discussed in the *micro-* and *meso-level* sections, the disclosure of data sets should not be compulsory if it would entail a competitive disadvantage and decreasing incentives for future investments for the affected actors. Moreover, within *horizontally convergent digital infrastructures*, guaranteed QoS-levels should be accepted – e.g. for safety- or health-critical data (cf. Newe 2014), as long as the unequal treatment of data is executed in an application agnostic manner (cf. van Schewick 2015).

### ***Service-Perspective on the Macro-Level***

In the context of *horizontally convergent digital infrastructures*, the realization of cross-domain services depends on a comprehensive orchestration of various functions from heterogeneous domains, based on a virtualized representation of these functions on a digital layer (cf. the *technology-perspective* of this chapter). While in *vertically convergent digital infrastructures*, the service provider acts as an intermediary of a variety of different stakeholders *within* a single, yet vertically convergent domain, the operators of smart service platforms, based on *horizontally convergent digital infrastructures* act as shaper of a smart service ecosystem that integrates services *across* several domains.

Similar to the assumptions on the *meso-level* of analysis, due to the significant level of market power, the operator of a cross-domain service platform (e.g. the shaper of a smart city platform or -ecosystem) could discriminate potential function providers by blocking them or setting prohibitively high prices for an participation as adopter and, as a result, prevent them from playing an active role in a platform ecosystem. Therefore, in order to safeguard a high variety of complementary providers of smart service functions and to incentivize potential entrants to participate in the horizontally integrated ecosystem, a *cross-domain platform neutrality* is recommended.

#### **4.4. Summary of the Analysis**

By analyzing convergent digital infrastructures in the mobility domain on a *micro-, meso-* and *macro-level*, we derived distinctive extensions to the concept of neutrality from a *technology-, data-,* and *service-perspective*. Figure 8 summarizes the identified concepts, taking the levels of analysis and the perspectives on digital infrastructures into consideration.

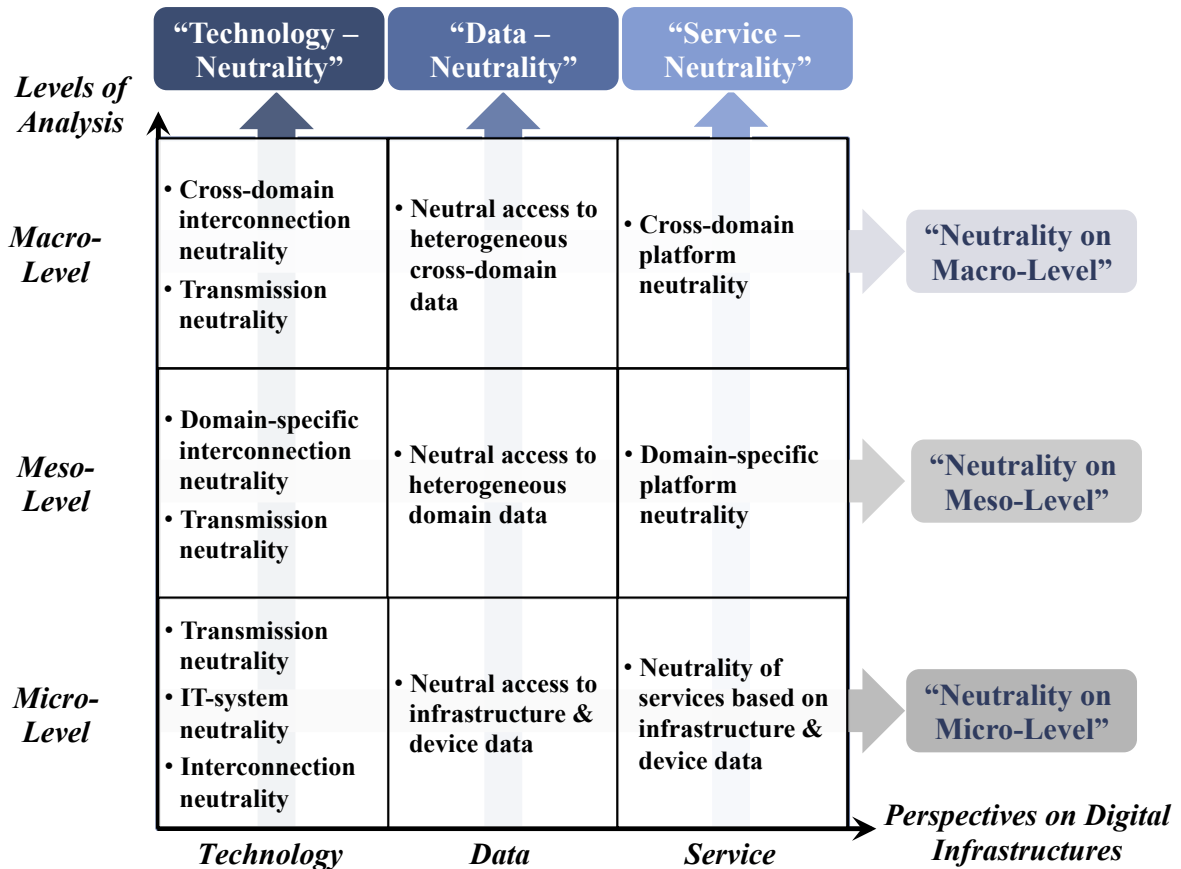


Figure 8: Identified Extensions to the Concept of (Net-)Neutrality (Own Illustration).

While the presented extensions in the context of *technology neutrality* primarily refer to the non-discriminatory access to different transmission networks, to an assured overall-interconnectivity, and to IT-systems that are open to applications from various providers, the *data neutrality* focuses on the generally equal treatment of the transferred data and the neutral access to it. The *service neutrality*, instead, takes particularly the rising importance of data- and service platforms into account, while emphasizing their non-discriminatory character in terms of participation and accessibility. It is important to note, however, that the identified extensions may not be interpreted in a narrow or strict manner, as the analysis showed that for each of the neutrality aspects deviations do exist. Although the identified extensions to the concept of (net-)neutrality are derived in the context of mobility, they can generally be transferred to other domains (e.g. the energy-, health care-, or education sector) as the transformation process of their underlying infrastructures, from previous analog to *horizontally convergent digital infrastructures* follows a similar logic. Moreover, the design of the conceptualized research framework with the three generic perspectives (*technology-*, *data-*, and *service-perspective*) and the corresponding levels

of analysis (*micro-, meso-, and macro-level*) is not directly linked to a distinctive domain or sector and, therefore, universally applicable.

## 5. Conclusion

The primary aim of this paper is the derivation of distinctive extensions to the concept of net neutrality. Therefore, after defining the trajectory from analog to *horizontally convergent digital infrastructures* and discussing the fundamental characteristics and assumptions of the classic view on net neutrality, we develop a novel, case study-based approach that divides the field of analysis into three predefined levels (*micro-, meso-, and macro-level*) and allows an investigation of the specific requirements to implement such convergent infrastructures from a *technology-, data- and service-specific* perspective. Based on the analysis of the mobility sector as primary field of investigation, distinctive extensions to the existing view on net neutrality are defined that contribute to the already existing claims for the conception of a more holistic view on this topic.

The study reported in this paper contributes to the existing academic literature on digital infrastructures and net neutrality in several ways. First, we introduce three generic steps to structure the evolutionary process from previous analog to *convergent digital infrastructures*. Thereby, we also refer to the emergence of novel, cross-domain applications and provide insights to the enormous potentials but also to major prerequisites and challenges for realization. Second, by proposing a research framework that splits the field of investigation into a *micro-, meso-, and macro-level* and allows an analysis from the *technology-, data- and service-specific* perspective, we offer an approach that can easily be transferred to future studies, focusing on *convergent digital infrastructures* in other domains than mobility. Third, the identified extensions to the concept of neutrality as result of analyzing convergent infrastructures in the context of mobility and the identification of gatekeepers beyond the ISPs on the (network-)infrastructure-level, contribute to the existing economic and institutional discussion by taking up the already apparent tendencies and claims in the academic literature for a more holistic view on this topic.

Moreover, this article is also of high practical relevance, particularly for decision makers from the mobility sector, as we not only elaborate important *technology-, data-, and service-specific* prerequisites and potentials that become relevant in the evolutionary process towards *converged digital infrastructures*, but also refer to changes in customer preferences and highlight the need for shifting the focus from single physical products like cars towards a systemic way of thinking of mobility services in cross-domain solutions, based on *convergent digital infrastructures*.



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