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Internet of Things, Virtual Networks and the Economics of Shared Mobility

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Abstract

In this paper the potentials for shared mobility services based on ICT innovations are characterized, requiring a paradigm shift from intramodal transportation markets to intermodal shared mobility markets. Heterogeneous ICT innovations are described, entailing various combinations of app-based mobile communications, (camera-based) sensor networks and big data processing. The potentials of shared mobility concepts to avoid traffic collapse and significantly reduce congestion and pollution in cities are considered, referring to different simulation studies on the impact of complete or partial replacement of private vehicles in a city with shared mobility services. Furthermore, the changing role of regulations in the context of the transition from traditional intramodal transportation markets to intermodal shared mobility services markets is considered. Firstly, it is necessary to abolish legal entry barriers to the local taxi market and the public transit market. Secondly, competition for subsidies of politically desired non-cost covering (shared) mobility services should be symmetrical for all active and potential providers of shared mobility services. Thirdly, technical regulation and consumer protection including privacy and cybersecurity for the shared mobility markets should be applied symmetrically and consistently. Finally, the role of pilot projects to establish shared mobility concepts are demonstrated.

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1. Introduction

The Internet of Things (IoT) is becoming relevant in all areas of the app economy of the future, such as smart grids and microgrids, smart sustainable cities, e-health, e-manufacturing, etc. (European Commission, 2015; OECD, 2015). By far the most important growth of the IoT is expected in the transportation markets (Winchcomb, Massey & Beastall, 2017). From a network economic point of view understanding the complementarities between innovative physical network services on one hand and the required virtual networks on the other is of particular importance (Knieps, 2017a, 2017b).

Congestion and air pollution create major problems in metropolitan areas worldwide, strongly driven by rapidly growing private car traffic. According to the Focus Group of Smart Sustainable Cities (FG-SSC) of the International Telecommunications Union sustainable urbanization is becoming a major challenge worldwide, which proves the need for innovative, sustainable cities to exploit the potentials of modern information and communication technologies (ICT) (ITU-T 2015). Although political debates on the pros and cons of driving bans for private cars in cities where air pollution exceeds limit values or of making public transit free of charge are topical, the focus of this paper is on the potentials of market driven shared mobility concepts aiming to reduce congestion and pollution in metropolitan areas.

Shared mobility may be characterized as an “envelope concept” focusing on innovative transportation services provided by a combination of ICT with infrastructures, transportation systems, operator platforms, and fully automated (driverless) vehicles, based on real-time and location-based data logistic management. From an economic point of view the conceptual differentiation between physical transportation services (e.g. car sharing, bike sharing, ride sharing, ride sourcing services/Transportation Network Companies (TNC), microtransit, bus-on-demand services, shared taxis) and complementary virtual networks based on sensor networks, mobile communication, big data analysis and interactive machine-to-machine communication (IoT) gains importance. Due to the variety of ICT-based mobility services, the characteristics of complementary virtual network logistics also vary, depending on real-time data and geo-positioning, dynamic changes of the state of the devices, relevance of data transmission for many users (e.g. in the context of cloud computing) etc. It is demonstrated that the complexity of virtual networks increases from peer-to-peer app-based car sharing networks, to app-based ride sourcing platforms (commercial transport apps), open data-based congestion management, and further to highly interactive, driverless vehicles. These heterogeneous physical mobility services can all be provided on the basis of IP-based virtual networks requiring

an innovative combination of (camera-based) sensor networks and location-based real-time communication with different traffic quality guarantees within an integrated All-IP communication network. Driverless vehicles require ultra-low latency guarantees for data packet transmission and big data analysis for the compressing of camera-based sensor data with strict positioning accuracy. It is to be expected that ICT-based shared mobility concepts will become a driver for innovative solutions to exploit the comparative advantages of different forms of public and private mobility concepts.

The future potential of shared self-driving vehicles is receiving increasing attention, with the function of driver responsibility shifting to a platform operator for the transportation process. The question as to what extent fleets of driverless cars could replace public transit by bus or train is currently the subject of controversial debate worldwide. The paper points out the important role of a market driven search process which may result in a multiplicity of local/regional solutions strongly based on the historical path dependency of public and private transit.

The paper is organized as follows. In section 2 the potentials for shared mobility services based on ICT innovations are characterized; this requires a paradigm shift from intramodal transportation markets to intermodal shared mobility markets. Heterogeneous ICT innovations are characterized, entailing various combinations of app-based mobile communications, (camera-based) sensor networks and big data processing. In section 3 the potentials of shared mobility concepts to avoid traffic collapse and significantly reduce congestion and pollution in cities are considered, referring to different simulation studies on the impact of complete or partial replacement of private vehicles in a city with shared mobility services. In section 4 the focus is on the implementation of market driven shared mobility. The changing role of regulations as requirement for the transition from traditional intramodal transportation markets to intermodal shared mobility services markets is considered. Firstly, free entry and competition in shared mobility markets requires the abolishment of legal entry barriers in the local taxi market and public transit market avoiding regulatory market splits. Secondly, competition for subsidies of politically desired non-cost covering (shared) mobility services should be symmetrical for all active and potential providers of shared mobility services. Thirdly, technical regulation and consumer protection including privacy and cybersecurity for the shared mobility markets should be applied symmetrically and consistently. Finally, the role of pilot projects to establish shared mobility concepts are demonstrated. Section 5 summarizes the conclusions.

2. ICT innovations and the changing markets for transportation services

2.1. Characterization of physical shared mobility services

Shared mobility services provide transportation services without requiring individual ownership of the vehicles for exclusive use. Shared mobility services can be non-commercial (e.g. reciprocal ride sharing organized by a peer group) or it can be commercial. There are many forms of commercial provision of shared mobility services either by small scale vehicles (cars, minibuses, bicycles) or mass transit of large capacity transportation (e.g. trains, subways). The owner of a car may rent his vehicle out for others to use for limited periods of time, or offer taxi services organized by a ride-sourcing company/TNC); vehicles may be owned by a platform operator organizing on-demand transportation services or may be in shared ownership organized on a peer-to-peer basis; alternatively vehicles may provide rail and bus transit: "rail and bus transit were the most frequently used shared modes, followed by bikesharing, carsharing, and ridesourcing"(Feigon & Murphy, 2016, p. 7). On-demand mobility can be provided via self-service concepts or for-hire service concepts. For fully automated (driverless) vehicles the concept of self-service is changing, because the real-time driving activity is no longer performed by the driver, but shifted to a platform. Shared mobility service options include membership-based self-service models, non-membership based self-service models, peer-to-peer self-service models, for-hire service models, ride-sourcing TNCs, and mass transit (Transportation Research Board, 2015, pp. 1-22; US Department of Transportation, Federal Highway Administration, 2017, chapters 1, 2).

An important consequence of shared mobility is the convergence of intramodal transportation markets towards intermodal shared mobility markets. The traditional perspective of considering rail transport, bus transport, and car transport as separate markets is shifting, making way for the concept of markets for shared mobility services. An evolving multiplicity of combinations between shared mobility services provides substitutes for individual private car trips – such as taxis, car rentals, car sharing, minibuses, buses, and high capacity public transit with trains, subways or tramways. The smaller bundling advantages of shared cars and minibuses may be combined with the greater bundling advantages of buses and the yet greater bundling advantages of high capacity public transit by providing seamless shared mobility service networks. Boundaries are beginning to blur between shared on-demand mobility services (e.g. bus-on-demand services) with flexible stops and routes, and public transit with scheduled

(timetabled) services with fixed stops and routes. Shared mobility can extend the scope of public transit, providing feeder services for public transit by tackling the first-and-last-mile problem (US Department of Transportation, Federal Highway Administration, 2017, p. ix).

The emergence of new mobility solutions using shared automated vehicles and their impact on future mobility markets in urban areas are investigated worldwide (e.g. OECD/ITF, 2015a). It is expected that transit providers willincreasingly be managing smaller, automated on-demand vehicles. Suburban areas might benefit from completely new transport options as alternatives to the private car. Increasing congestion management and dynamic road pricing create incentives for shared automated vehicle-based mobility services in suburban areas (OECD/ITF, 2018, pp. 14f.; Helsinki Regional Transport Authority (HSL), 2016a).

2.2. Characterization of virtual networks for shared mobility services

Although there are different types of shared mobility services with heterogeneous ICT requirements, they all typically rely on real-time, location-based information to enable app-based operating platforms coordinating and organizing the on-demand provision of mobility services. Examples are bicycle sharing, car sharing, ride sharing, ride sourcing, minibus-on-demand with virtual stops and flexible routes, driverless shared mobility services, and (high capacity) public transit. On-demand mobility services require real-time, location-based mobile communication services combined with mobility apps. App-based mobility services result in a convergence of transportation services provided by taxis, private hire vehicles and ride sourcing platforms (commercial transport apps) (OECD/ITF, 2016c).

Virtual networks for shared mobility services are based on combinations of real-time mobile communications, global navigation system services (geopositioning) and sensor generated data processing (OECD/ITF, 2015b, 2016b): Infrastructure-generated data are increasingly replaced by sensor-generated data via mobile phones, on-board navigation devices and vehicle-to-vehicle communications. ICT for shared mobility services are based on multi-platform sensoring technologies as well as data storage and transmission capacity in vehicles able to precisely locate and track people and vehicles supported by the Global Navigation Satellite Systems (GNNS). Examples for location-based data services are taxi-hailing apps and ride-hailing apps, road navigation and multi-modal routing services and multi-modal big data processing (OECD/ITF, 2016b; GNNS, 2017).

Anonymized smartphone data generated by a large number of trips operated via taxi or ride sourcing platforms enable the setup of "open traffic" global platforms with big data processing capabilities for anonymous positioning of vehicles and smartphones, providing information on traffic speeds and traffic patterns on road segments. Starting with a cooperation between World Bank's Big Data Challenge Innovation Grant and Grab Taxi, an on-demand taxi service generating taxi GPS data in countries the World Bank supports, an important goal has been peak-hour traffic analysis along key streets in selected Asian Cities (World Bank, 2015; OECD /ITF, 2016b, pp. 31f.). In the meantime, several ridesharing companies and navigation service companies have together founded the Open Traffic Partnership platform to build a global architecture for sharing anonymized traffic data. Open Traffic Partnership is a multi-purpose platform aiming to support intelligent transport systems such as traffic signal timing plans, public transit provision, emergency traffic management, travel demand management and roadway infrastructure requirements.[1] Waze App platform, a navigation system for smartphones, enables sharing of real-time location-based traffic information consisting of navigation information and user-submitted travel times and route details. Location-dependent information is provided over a mobile telephone network via a community-driven GPS navigation app, which is free to download and use. App-based sharing of publicly available real-time traffic information is organized via the Waze App platform. In the context of its "Connected Citizens Program"[2] Waze provides a citizen-government data exchange platform to partner cities, providing those cities access to its data in real-time; this enables city authorities to identify congestion based on the analysis of users' GPS data. The goal of this public-private partnership is to improve the quality of Waze App by receiving local road sensor data, publicly available information on local incidents and road closure reports; the benefit for the partner city is the ability to utilize Waze data on the Waze App platform providing better information on current road conditions (OECD /ITF, 2016b, p. 32).

[1] The World Bank, Feature Story, Open Traffic Data to Revolutionize Transport, December 19, 2016, http://www.worldbank.org/en/news/feature/2016/12/19/open-traffic-data-to-revolutionize-

[2] For more information on the Waze Connected Citizens Program see https://wiki.waze.com/wiki/Connected_Citizens_Program

3. Potentials of shared mobility markets to substitute private car traffic and its impact on congestion and pollution

Private car traffic is the major reason for traffic collapse, serious congestion problems within cities and air pollution in metropolitan areas. A striking result of the analysis of average weekday travel speeds on major downtown streets in selected Asian Cities (e.g. Cebu City, Manila, Bangkok, Jakarta) based on real traffic data shows that heavy traffic congestion remains more or less constant throughout the day, so that peak traffic with a strong decline of travel speeds persists from early morning until late in the evening (World Bank, 2015, pp. 11-13).

The future role of shared mobility markets in reducing congestion and environmental problems within cities is therefore a challenging problem worldwide. The question to what extent shared on-demand mobility services such as shared taxis, taxi-buses or bus-on-demand shall substitute private car traffic is highly controversial. Moreover, the interaction between shared on-demand mobility services and high-capacity public transit by train, subway, ferry, and tramway plays an important role.

Real-time based centralized dispatched networked pooling of taxi services creates large potentials for a reduction of vehicular traffic congestion and air pollution due to large reductions of cumulated trip length; a 40 % reductions is expected based on a simulation study for the city of New York, but taxi pooling benefits would become important for all of the 83 largest urban areas of the U.S. (Santi et al., 2014). A simulation study has shown that automated centralized dispatched mobility-on-demand systems replacing all modes of private individual traffic in a city like Singapore could result in a vastly reduced fleet of cars whose size would be approximately 1/3 of the total number of private vehicles currently in operation (Spieser et al., 2014).

In recent years the International Transport Forum at the OECD carried out several simulation studies to investigate the impact shared on-demand mobility services would have on replacing other forms of travel and thus reducing traffic congestion and air pollution. Within a real urban context under application of real mobility and network data different reform scenarios have been analyzed, with particular focus on the complete or partial replacement of private car traffic by shared on-demand mobility services. It is assumed that a central mobility dispatcher coordinates the matching of shared vehicles to passengers, centralizing all real-time information and optimizing routes and stops to fit the transportation requirements of each passenger, according to a set of time-minimizing rules. Depending on heterogeneous travel

requirements different quality standards regarding travel time and travel duration may be offered. Shared mobility simulations were carried out for Auckland, New Zealand's largest city (OECD/ITF, 2017a), for Lisbon, a mid-sized European city (OECD/ITF, 2015a, OECD/ITF, 2016a) and a follow up study for the greater Lisbon Metropolitan Area (OECD/ITF, 2017b), and for the Helsinki Metropolitan Area in Finland (OECD/ITF, 2017c). Different scenarios are considered, differentiating for instance according to whether all private cars are being replaced or only a subset, whether all public transit trips with busses and rail continue or whether bus trips also are replaced by shared on-demand mobility services. Different shared mobility services are considered, typically with shared taxi (6 persons) and taxi busses (8-16 persons); only the first Lisbon study (OECD/ITF, 2015a) also considers the sequential individual transport ("AutoVots"). There is also differentiation regarding whether the shared on-demand mobility service is provided with fully automated (driverless) vehicles or with a human driver.

In a scenario where all private car trips are replaced by shared taxi or taxi bus and all other trips are taken via public high capacity transit, walking and cycling, the simulation studies all arrive at the same conclusion: congestion is strongly reduced or disappears completely, and pollution is also strongly reduced. For Lisbon it is shown that replacing all cars and bus trips with a fleet of six-seat vehicles (shared taxis) that offer on-demand door-to-door shared rides in combination with a fleet of eight-person and 16-person minibuses (taxi buses) the car fleet would only be 3 % of today's fleet and total vehicle-kilometers would be 37 % less than today (OECD/ITF, 2016a, p. 8). The benefits of shared mobility even increase, if greater Metropolitan areas are considered, due to the greater importance of shared mobility services in providing feeder services to public transit. But even if only 50%, or, respectively, 20 % of private car trips are replaced by on-demand shared mobility services and the bus services continue, there is still a significant reduction of congestion and CO_2 to be expected for the Helsinki Metropolitan Area (OECD/ITF, 2017c, p. 53). For the Auckland study it was found that if all today`s private car trips were provided by shared mobility services, congestion and emissions as well as distance driven would halve. Even if only a subset of car users were to switch to shared mobility services, a significant effect on congestion and CO_2 could be observed (OECD/ITF, 2017a, p. 6).

4. Towards the evolution of market driven shared mobility

4.1. Intermodal shared mobility markets and the challenges for regulations

Free entry and competition in shared mobility markets

Abolishment of legal entry barriers and regulatory market splits is unavoidable. Prosumer peer-to-peer activities as well as business-oriented market activities providing shared mobility can only flourish if all legal entry barriers in the markets for transport services are abolished. Market entry regulations with licenses and public price fixing such as in the German taxi market serve to establish cartels. Such market regulation does not only interfere with price competition and market driven entry and exit decisions, but also obstructs the search for new innovative mobility concepts. Due to app-based ICT innovations services provided by taxis, private-hire vehicles and ride sourcing services/TNCs (commercial transport apps) are converging and they belong to the same relevant market for individualized mobility. Entry regulations via licenses, geographic restrictions and fare setting for taxis are not only contrary to the general principles of open markets but also cause artificial regulatory market splits compared to private-hire vehicles and ride sourcing services (OECD/ITF, 2016c, p. 6). Moreover, competition between individualized mobility services and shared on-demand mobility services with shared taxis, taxi buses and bus-on-demand services should not be disturbed by regulatory market splits.

Competition for subsidies of public non-cost covering shared mobility services

The comparative advantages of different forms of shared mobility services are not only relevant in densely populated urban areas but also in rural areas with low population density. A major change is that the concept of “public transport” is no longer limited to scheduled services, but can also include on-demand mobility services (OECD/ITF, 2015c). If during certain time periods of the day demand is so low that offering scheduled train or bus services would result in large deficits, the publicly desired transport service could be provided by a shared minibus or shared taxi service; even individual ride sourcing trips should not be excluded. In the context of a transparent bidding procedure, the most cost saving public mobility service can be chosen, exhausting the comparative advantages of scheduled mobility services versus on-demand mobility services depending on the local/regional demand circumstances and thus minimizing public subsidies.

Technical regulations and consumer protection

Technical regulations in shared mobility markets focusing on health and safety as well as insurance and consumer protection through adequate laws and technical standards are gaining increasing relevance and raise controversial debates as to what extent additional rulings are necessary (Transportation Research Board, 2015, pp. 62-71). Other issues regarding the interaction of public and private spheres are parking and access to public space both for private businesses and for non-profit purposes with competing operators and transportation services as well as taxation on shared mobility. Data sharing (open data), data privacy protection and cybercrime protection are also gaining relevance. Of particular relevance is safeguarding privacy in the context of location-based mobility data (OECD/ITF, 2016b, pp. 21-26 OECD/ITF, 2015b, pp. 33-58).

4.2. Get the bandwagon rolling: The role of pilot projects

"Kutsuplus", the world's first pilot project providing a fully automated, real-time on-demand public minibus service with flexible routes and virtual stops started in 2012 in Helsinki. The project was initiated by Helsinki Regional Transport Authority (HSL) to provide incentives for substituting private car trips by on-demand minibus service, thereby reducing congestion and air pollution. Routes are optimized on the basis of real-time trip orders from customers using a GPS-enabled smartphone. Passengers with roughly the same pick-up and end-point locations are allocated to the same vehicle. The platform bundles all requests with similar routes and informs the users on the closest virtual stop. The transportation service of Kutsuplus offers a real-time based flexible choice of routes without fixed departure times and without fixed entry and exit points, comparable to a shared taxi service. The goal was to assess the technical feasibility of the project and to get experience on user acceptance during a period of three years. The Kutsuplus pilot project gained worldwide attention as an innovative forerunner ICT project which could provide new impulses to public transit with real-time on-demand service strongly reducing private individual car traffic. The pilot project was considered a success due to strongly growing demand and customer requests to extend the service areas. It became obvious that a further expansion of the service network would have required a significant increase from 15 minibuses to 45 in 2016 and to more than 100 in 2017.

However, the necessary investments could not be realized.[3] Nevertheless, the goal of HSR is to develop further shared mobility services based on more extended Kutsuplus-type services (Helsinki Regional Transport Authority (HSL), 2016b). Although the minibuses in the Kutsuplus pilot project were able to choose demand-oriented virtual stops and virtual routes on a fully automated basis, there were still drivers and they were a high cost factor. Therefore the start of a regular bus line in Helsinki with a driverless bus in 2017[4] may open up an interesting new perspective. In the meantime potentials for Kutsuplus-type bus-on-demand services are also considered in other towns; examples are St. Louis[5] and a ride-pooling-project in Hamburg, starting on January 2019.[6]

Shared mobility concepts need not necessarily be combined with driverless vehicles. Two topical initiatives in Switzerland are the ride sharing systems "Taxito" and "Publiride" enabling non-profit oriented peer-to-peer car sharing based on publicly subsidized app or SMS activated electronic display boards located at bus-stops (Publiride), or, respectively, a registration system operated by the Publiride platform provided by the public "PostBus Switzerland". It is expected that these publicly organized peer-to-peer car sharing systems will gain significant momentum to complement the public transit offerings during off-peak times in Switzerland.[7] In other countries such as the U.S. ride sourcing services (TNC) connecting drivers of personal vehicles with passengers using apps for booking, ratings and electronic payment gain increasing relevance for solving the first-mile/last-mile access problem to public transit.

Different locational environments require different solutions: High-capacity collective modes are more suitable for densely populated cities. Suburban areas benefit from completely new transport options such as bus-on-demand or shared minibuses.

Impact of automated vehicles on urban mobility: Importance for the first-mile/last-mile feeder functions to improve quality and comfort of mobility services compared to complete takeover

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[3] S. Egerton-Read: Why did Helsinki's on-demand mobility service fail?, Circulate, 6. Februar 2017, http://circulatenews.org/2017/02/finlands-kutsuplus-cautionary-note-promise-demand-mobility/

[4] City of Helsinki: Helsinki to Launch Self-Driving Bus in Regular Service, 15. Juni 2017, https://www.hel.fi/uutiset/en/helsinki/helsinki-self-driving-bus-regular-service

[5] J. Cohen: St. Louis Looks to On-Demand Transit for Downtown Mobility, Next City, 20. Februar 2018, https://nextcity.org/daily/entry/st.-louis-looks-to-on-demand-transit-for-downtown-mobility

[6] OIA: Wir sind behördlich genehmigt!, 26. April 2018, https://www.moia.io/de/blog/2018/wir-sind-behoerdlich-genehmigt/

[7] P. Schneeberger: Autostopp 2.0: Das Mitfahrsystem Taxito ergänzt Bahn und Bus in ländlichen Regionen, Neue Zürcher Zeitung, 12. Januar 2018, p. 14.

of urban mobility. The evolution of shared mobility service markets using automated vehicles requires a shift from the traditional intramodal oriented “public transport” and the development of innovative multi-modal systems and service concepts, which will increasingly consist of scheduled high capacity public transport and complementary on-demand small-scale private transport (OECD/ITF, 2018, p. 14).

5. Conclusions

For the US O`Toole (2017) expects that during the next decade shared driverless cars will become a superior alternative for publicly funded transit services in most areas outside the big cities. Although the future of shared mobility markets is unknowable, it can be expected that path dependency of traffic infrastructures, differences between topography, the interrelations between urban and rural areas etc. will result in various shared mobility concepts. The differences between dense urban areas with high quality public transport and non-existing demand for high capacity public transit in rural areas will lead to a variety of different mobility concepts (OECD/ITF, 2018, p. 31). But the differences between urban and rural areas are beginning to blur where urban services are expanded to serve wider metropolitan areas around the cities (OECD/ITF, 2017b) Thus the focus shifts to scaling up shared mobility services to the whole of the Metropolitan area, and new types of shared services arise. Shared taxis or taxi buses can provide feeder services complementary to existing high-capacity public transport networks (e.g. metro and rail lines).

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