



International Scientific Conference on Mobility and Transport
Urban Mobility – Shaping the Future Together
mobil.TUM 2018, 13-14 June 2018, Munich, Germany

Drones for last mile logistics: Baloney or part of the solution?

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Peer-review under responsibility of the scientific committee of the mobil.TUM18.

Keywords: drones; last mile delivery; city logistics; urban freight; radical innovations; evolution of transport systems

Road-based mobility is increasingly under pressure, with remarkable dynamics in the last decade in terms of pollution, congestion, speed delivery expectation etc. Such pressures point to a limitation of the efficiency of road-based mobility for further economic and social development. A mainstream solution is considered by electrified, automated mobility-services based on the road transport. This article discusses an alternative future pathway based on an evolutionary economic perspective. The case study employed concerns “drones for last-mile logistics”. The analysis makes clear that current efforts to enhance efficiency by electrifying and automating the established vehicle technology are short-term solutions. The main concern in the article is to broaden the policy-supported search for future mobility solution. The disruption of efficiency limitations is the key to sustainable social and economic development.

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1. Introduction

An efficient transport system is the backbone of a modern society and its economy. In broad terms, the efficiency of transport systems comprises direct transport costs, external costs (pollution, congestion, etc.), accessibility, and infrastructure utilization. Today, individual transport is generally based on combustion engines; passenger cars and trucks are the dominant forms of mobility. A so-called “regime” has been configured where the decentral alignment and the co-evolution of industry, policy, science, infrastructure, user and usage culture, markets and market rules (Geels 2002, 2005) have made “road-based” mobility a factor of growth, employment, culture, and everyday life. But this dominant transport regime is under pressure: legislation demands zero-emission vehicles, many roads are notoriously congested, and the increasing digitalization of society and the economy requires new levels of speed, flexibility, and individuality in physical and non-physical mobility. Particularly in growing cities, this pressure culminates in mass effects. The efficiency of road-based mobility seems to be limited.

The established automotive regime offers solutions: automated and autonomous driving vehicles, mobility as a service, and electrifying the drive train are elements of the mainstream vision of future transport. However, we currently can observe a new level of dynamic in the transportation sector. Further solutions to counter the pressure come from inventors and innovators: alternative means of transportation such as electric cargo cycles, ground and airborne drones are being considered as new transport options. Furthermore, airships have been reinvented, and more radically, tube concepts – namely the Hyperloop, CargoCap or Cargo Sous Terrain – are being designed to transport people and cargo at high velocity and are attracting scientific and entrepreneurial attention.

In history, well-established transport regimes have repeatedly been ousted by disruptive inventions that make tremendous efficiency gains in contrast to the established one, e.g. the transition from non-motorized transport (by foot and carriages) to the railway and tram system. Nearly one hundred years later the railway system was challenged by the horseless carriage which then became the dominant transport mode.

General features for such transitional situations include, firstly, a dominant transport regime facing growing pressure that comes up with solutions for further efficiency improvements. But such improvements are based on the established technology and are only implemented incrementally (Heinze/Kill 1989, Geels 2002). Such regime’s efforts have indeed led to a decrease in generalized costs for users and an increase in generalized transport systems’ capacities. However, such incremental improvements have only been able to stave off the limits of growth temporarily, but not resolve them. For example, by approx. 1880, the electrification of the railway system and the introduction of trams improved the transport system’s efficiency (an increase in capacity, a decrease in pollution, etc.). But such improvements were not able to provide a solution addressing the desire for individual mobility and other requirements, resulting in pressure on this regime (Geels 2005). Secondly, genuine efficiency gains have been made by disruptive niche technologies. These efficiency gains were achieved in almost all economic sectors and helped create a general economic upswing (Kondratieff cycle). In the 1920s, the car and the truck were such niche technologies, providing disruptive efficiency gains compared to collective transport, i.e. the railway system. Cars and trucks could improve the accessibility of locations which were not directly located near the railway tracks, this being their specific niche to grow out from (Geels 2005).

Considering the situation of pressure and dynamic in transport regimes today outlined above, it seems most probable that mobility-as-a-service concepts (automated and electric) will be part of future transport. The dominant regime (road-based mobility) is moving in this direction in order to obtain further efficiency gains resulting in decreased generalized transport costs and increased capacity. However, such a form of mobility will not decrease transport demand and will not result in congestion-free cities. Derived from the aforementioned descriptions, the decisive questions today are:

1. *Is a new disruptive gain in efficiency required and possible?*
2. *Which kind of infrastructure enables such efficiency gains?*
3. *From which niche will these efficiency gains grow?*

Against this backdrop, we discuss airborne drones as a future competitive alternative to the established car/truck regime. This paper argues from an evolutionary economic point of view and aims to introduce a different perspective to the societal and political discourse on future mobility solutions, and investigates disruptive (innovative) transport technologies and their potential to establish a new transport system (post-car mobility)

through massive efficiency gains. The analytical approach is based on the concept of transport systems' evolution (CTSE), introduced in section 2. In section 3 we apply the CTSE to urban freight transport as a case study to provide a deep understanding of the dynamics today. The paper then discusses the potential of airborne drones as an analytical example in section 4. The conclusion contrasts past insights with current policy options.

2. The logic and systematics of transport system's evolution

Comparing the early truck technology of the fifties with its performance today, we see a massive difference in speed, capability, service range, etc. The truck evolved over time. Müller and Liedtke (2017) developed an approach explaining the logic and systematics of the evolution of transport systems which we apply in this paper. The approach applies a multi-level perspective (Geels 2002) to transport by incorporating innovation theories, industrial economics, and empirical findings. This approach can thus be understood as a micro-foundation of the multi-level perspective (MLP) by industrial economics and innovation studies. The CTSE covers three aspects of transport system's evolution: firstly, the development of a transport system; secondly, the mutual interdependence of transport systems in their development; and thirdly, the interaction of the transport system's evolution with the socio-economic landscape.

2.1. The evolution of a transport system

According to Müller and Liedtke (2017), there are four phases in the evolution of a transport system: 1) stabilization of a disruptive technology, 2) technology transition, 3) growth, and 4) degeneration. These four phases are characterized as follows:

Evolutionary phase 1 - the stabilization of a disruptive technology: In the first evolutionary phase, inventors and entrepreneurs try to launch disruptive technologies in the search for suitable - mainly technological - solutions to current challenges in real market application; for instance, the need for a transport system for mass goods during the ongoing industrial revolution at the beginning of the 19th century led to the invention of the railway system. Typically, this is a process of trial and error: the technology is tested in market niches where a solution is really needed. Once a technology design successfully fits user needs, the techno-organizational configuration is locked-in (Cowan 1996, Sydow et al. 2009). The phase of stabilizing technology describes the route to this lock-in. The lock-in implies a path dependency and a path interdependency in future; the actors do not change the basic functionality in future but incrementally refine the technology (Cowan 1996). Each transport system known today is based on a once-disruptive new technology. For example, rail is based on steam-powered carriages on iron tracks and was disruptive to horse carriages. Automobiles, as a second example, were no longer limited to the use of tracks – that was disruptive to rail technology. The invention of the technology itself always occurred decades before becoming economically relevant in any way.

Evolutionary phase 2 - the technology transition: This involves the replacement of one technology regime by a new one. A technology regime is the alignment of actors, rules, and behavior in the sphere of a technology such as the supply industry, policy, science, infrastructure, markets, and culture of usage (Geels 2002). In this phase, the new transport system (stabilized in phase 1) serves growing demand from the niche market and can exploit the so-called attacker's advantage (Christensen and Rosenbloom 1995). This effect comprises a) the existence of unsatisfied but growing demand, b) the innovation pathway of the regime being unable to serve this demand or having to be drastically re-aligned by the regime members to serve it and, most important, c) the capacity for improvement of the new technology being drastically underrated while the potential improvement of the established technology is drastically overrated by the dominant regime. This is explainable with the law of diminishing marginal improvements: the established technology is optimized over decades and the outcome of improvement by capital input (both financial and knowledge capital) becomes lower and lower with increasing degrees of optimization. In contrast, the new technology is at the beginning of this development. Thus, when expectations of future growth

concentrate on the new technology, the capital (financial and human capital) shifts to this technology as well. The new technology is vastly improved by capital input and the technology transition takes place.

Evolutionary phase 3 - the growth of a transport system: After the technology transition, society and the economy are slowly restructured around the new technology. Creative usage finds more and more deployment fields and, with time, the new dominant technology creates its own demand. For example, the demand for leisure and holiday trips or logistics services evolved as a “car-technology specific demand” or “truck-technology specific demand.” The regime initiates and fixes its structural path interdependency, i.e. value chains, infrastructures, political networks, science, markets, user preferences, and cultural integration, establishing itself as a dominant technology (see Geels 2002). Christensen (1997a) has postulated a form of product competition that lays out a regime-conforming technology development pathway, based on 1) product functionality (basically done during the first two evolutionary phases) 2) product reliability 3) product convenience and 4) product price. Normally, alternative pathways are excluded from this product innovation competition because they would destabilize the market, market position, profits, patents etc. – the regime’s economic base. Thus, the dominant technology regime tends to intensify improvement innovation, resulting in an overshoot of demand needs, disharmony between technology, over-engineered supply, and real demand development. The pattern of product competition and the inability to include disruptive innovations in the development pathway characterize the so-called innovator’s dilemma, which makes established firms fail (Christensen 1997b).

Evolutionary phase 4 - the degeneration of a transport system: At the beginning of this phase, the demand that has developed can be satisfied by the transport system. However, demand is saturated, and the technology was thoroughly optimized within the growth phase. According to the innovation competition pattern, price competition has started and thus, the price is or is close to the level of marginal cost (without price-fixing cartels). However, negligible margins in a saturated, non-growing market impede innovation, because the expectation of a return on investment is very low or at risk. But, without innovation, the market loses its dynamism and a spiral downwards is unleashed: no expectation for market growth means no return on investment and thus no innovation activity and, in turn, no innovation activity means no further market growth. Mensch (1975) labeled such a situation a stalemate in technology, which denotes a degeneration of markets. According to Mensch, the stalemate is only conquerable by disruptive new technologies. Such technologies offer new productivity levels, user groups, and deployment areas and, therefore, new growth expectation leading to innovation activities (see phase 1). If no disruptive technology enters the marketplace, the transport system either disappears from the market by market forces (such as horse driven tramways) or degenerates to a niche market (such as horse driven carriages as the dominant urban transport system in the 19th century nowadays only being used for tourism or sports). Alternatively, as a transport system diminishes, its status can be subsidized by the state (such as for freight rail services in Europe).

2.2. The mutual interdependency of transport system’s evolution

The four phases of evolution described above characterize the pathway of each transport system. However, in a market such as continental freight services, transport systems’ phases are always offset. Because of the theoretical effects of each phase (lock-in, attacker’s advantage, innovator’s dilemma, stalemate in technology), the conditions for other transport systems are mutually interdependent; the rise and fall of transport system regimes is thus systematic. According to Müller and Liedtke (2017), the systematics of the offset are:

The growth of the dominant transport system and the stabilization of another: The growth of a transport system is focused on the core user of the mass market, supplied by the functionality of the transport system. However, this growth opens market niches. These are markets where other functionalities are required which cannot be supplied by the mass market technology. Due to the difference in functionality, niche market requirements cannot be served by mass-market producers and their product innovation pattern. As the system becomes locked in, new players with disruptive technologies discover this demand and ways to serve it. For example, rail is dependent on tracks and cannot, or can hardly at all, serve the space not covered directly by the tracks. This market niche was discovered by entrepreneurs with car’s and truck’s technology. Niches for radical new transport systems are thus systematically created by mass market technology’s characteristics and mass market growth.

The technology transition of a disruptive transport system and the degeneration of another: When the technology is

optimized throughout, the improvements by capital inputs become smaller. However, new demand from niches rises and the marginal improvements by innovations are quite high. The dominant regime now competes with the niches by utilization of market power and political collusion. Since i) the marginal gains are higher for the disruptive technology than for the dominant one, ii) the growing niches cannot be served by the functionality of the dominant technology, and iii) the dominant regime faces the innovator's dilemma, the attacker's advantage for the new technology inevitably leads to a technology transition. Thus, by the successful diffusion of a new technology from a niche market to a mass market, the former mass market technology is pushed into its degeneration phase. An example is the degeneration of rail with the success of the car.

The degeneration of a transport system and the stabilization of another: In the degeneration phase a technology is inevitably in a stalemate. In this situation, the technology would either be subject to market-correcting forces or be protected from them by governmental measures. In the latter case, the stalemate situation would continue. The way out of the technological stalemate is generally believed to succeed only through a disruptive innovation. This can be found in niches, with frequent attempts to improve a transport system - from its growth phase and more recent inventions. This offset of phases is thus a special case because the degeneration remains until a disruptive technology is applied as a game changer.

2.3. Interaction between the evolution of transport systems and the socio-economic landscape

According to the MLP, the landscape plays a major role in technology transitions. The landscape comprises deep structural trends such as economic development, social paradigms, or wars. These trends put pressure on the regime, slowly or spontaneously, and result in the requirement for a dominant technology regime adapting the pressure. In his triple embeddedness framework (TEF), Geels (2014) distinguished between socio-political and techno-economic pressure on a technology regime. However, the socio-political and techno-economic pressures have different implications for a technology regime and its innovation pathway.

The techno-economic pressure relates to disruptive innovations, implying a new paradigm. Amongst other things, such innovations change labor skill profiles, demand patterns, the competitive base for companies' products and production methods, and the growth of new market players (Freeman and Perez 1988). Such innovations include: the steam-driven spinning machine (industry sector), railway (transport sector), electricity (energy sector), motorized vehicles (transport sector), and information and communication technologies (telecommunication sector). Disruptive innovations are game changers, their effects on the landscape are tremendous, and thus the influence of disruptive innovations outside the transport sector puts pressure on the transport system to adapt. A transport regime has great advantages when adapting to such techno-economic pressure. Firstly, such transportation-external disruptive innovation provides new and paramount input factors. This can lead, for example, to enhanced efficiency in production methods. Secondly, such innovations define the new paradigm of the society and economy and thus also the orientation of the transport mass market needs. There is an inherent incentive for the transport regime's businesses to be in line with this paradigm or with changing demand. Thirdly, after 40-50 years of an economic upswing (related to a duration of a Kondratieff cycle) of one transport regime, the situation often ends up in an economic crisis and downswing. For the worldwide automotive industry, for example, there was a notable downswing in the 1980s, with a deep crisis for American and European manufacturers. Aligning products with the new technology and its economic upswing is a way to be part of the growth, as was the case for the car industry with the availability of capable information and communication technologies (latest Kondratieff upswing since the 1980s). The technology will most likely be integrated in the competition for reliability and convenience. The pattern of integration corresponds to Barras' reverse product cycle (RPC; Barras 1986) because the transport sector is then a user of external technologies. The RPC says that first the new technology will be applied to improve the efficiency of the existing ones; secondly, quality improvements are addressed and finally new products will be developed by the external technology.

The socio-political pressure rises as a technology's negative impact grows and the technology shows itself unable to solve it. For example, pollution, noise, and congestion are congruent with the success of cars and trucks. However, in contrast to the incentive to address techno-economic pressure in the incremental pathway of a transport regime, it is rather unattractive in the case of socio-political pressure. The first reason is the free rider problem.

Addressing social benefits in a single company's innovation strategy brings no return on investment. Rather, other companies would benefit from incremental improvements without investment and risk. Secondly, it would need a radical change of the incremental innovation pathway, because if the incremental pathway had addressed it, it would not have become a pressure. It thus would require a break-up of the lock-in of firms and other regime elements. This is related to risk, sunken costs and new, uncertain investments. Thirdly, the pressure increases from a niche to a mass pressure (for example environmental issues surrounding the car in the 70s), however, do not represent the core market or the mass market of a regime. The incentive for risky investments and failure for a relatively small niche demand is very low. Fourthly, the existing power of the network, since politics and users are also part of the regime, make the industry regime believe in a successful fight against the pressure of campaigns, the influence of laws and market rules. For these reasons, it is unlikely to address socio-economic pressure but likely to address techno-economic pressure for a transport regime. Instead, according to the TEF (Geels 2014), four stages characterize the scope of the pressure: 1) denial of the problem, 2) local search for solutions, 3) distant search for solutions, and 4) a path re-creation with a solution. The fourth stage is unlikely, as argued above.

3. Understanding the dynamics of transportation today: the case of urban freight transport

On city roads, freight and passenger transport share the same infrastructure, act in a similar formal framework, and interact with and suffer from inefficient infrastructure conditions. We shall now apply the concept of transport systems' evolution to urban freight transport for the purpose of analyzing the status quo of urban transport. The provided findings are transferable to passenger transport, too.

In line with the CTSE introduced above, we consider three analytical levels: i) the pressure from the landscape on the state of practice, ii) the evolutionary phase of the dominant freight transport regime, and iii) the dynamics in niches.

3.1. The pressure from the landscape level

The pressure from the landscape level is distinguished by the techno-economic pressure and the socio-political pressure on the current state of practice. The two pressures are described as follows:

3.1.1. The techno-economic pressure on the current state of practice

Information and communication technologies (ICT) have changed and shaped the world tremendously in the past 30 years. "Digital Society" and "Industry 4.0" express the distinction of what has come since the success of the computer and internet in terms of technology diffusion, integration, skill profiles, user behavior, production methods, substitution of obsolete products, market actors, rules and power structures, etc. ICT implies a new societal and economic paradigm (see Freeman and Perez 1988).

The changes caused by ICT in freight transport technologies and practices are most strongly felt by a rapidly growing e-commerce market. Products become instantly available "on-demand." Sir Richard Branson has stated: "The global growth of e-commerce is driving a dramatic shift in both consumer and business behavior. On-demand deliveries are a novelty today. Tomorrow it will be the expectation." (Branson 2018). Online orders have undergone double-digit increases for the last decade. Parcel service providers (carriers) benefit from this growth as they fulfill the delivery chains from shippers to receivers. However, in consequence, the established techno-organizational fulfillment of the last mile delivery is trimmed: 1) shipment sizes decrease, resulting in more parcel drops and pickups per tour. For example, in the B2B sector expensive store space for stock is optimized, meaning shops require deliveries a couple of times per day. 2) A growing number of parcels need to be delivered within a smaller time window, consequently increasing the number of delivery staff. That means more vehicles are needed for the same number of parcels. 3) Online retailers offer instant delivery within 60 to 90 minutes after finalizing an online order. This implies either disruptions in tour organization or vehicle deployment dedicated for instant tours.

In the condition of the growing parcel market, it is highly attractive for service providers to be more temporally and spatially flexible for e-commerce customers. However, there are also challenges for the established state of practice in terms of the temporal and spatial limitation of trucks tours and parcel deliveries. Overall the developments outlined here entail changes in transport demand which can be fulfilled less and less adequately by established logistics and delivery concepts/technology. The socio-political dimension only makes this pressure stronger.

3.1.2. The socio-political pressure on the current state of practice

Congestion, pollution, greenhouse gas exhaust, noise etc. have been known consequences car and truck mobility for decades. For example, the ground-breaking 1961 Buchanan Report “warned the audience that ‘terrible things are coming to pass as a result of the influence of the motor vehicle’. Cars, in particular, were ‘now threatening the civilized functioning of urban areas (...)’” (Gunn 2011). Note: this report stems from a time when the automotive industry was driving economic growth and social welfare in western countries. A result of this report was the introduction of integrated transport policy, aligning town planning, traffic engineering, land-use management, and environmental management, with car-friendly cities being shunned (Gunn 2011). However, the ongoing mass effect (success) of cars has made it necessary to address these effects sharper today.

Narrow streets, mixed traffic, and congestion especially characterize urban areas, and it is, therefore, difficult to keep inner-city deliveries and pick-ups reliable, affordable, and fast (Verlinde 2014). Without a doubt, congestion through high traffic numbers has a tremendous negative impact on the life quality of inhabitants or on productivity within a city. The respective shares of transportation types (e.g. personal and public transportation, as well as freight transport) differ from region to region. Particularly in fast-growing mega-cities of developing and threshold countries, the problem of congestion hinders economic development and has enormous ecological consequences (Muñuzuri et al. 2012). Fulfilling the promised delivery time is barely achievable for the carrier. The capacity of the streets is saturated and usually there is no space (nor will or money) to add more driving lanes today.

Some urban congestion mitigating strategies have been introduced worldwide. “Congestion-charging” is expected to change market participants’ perception and behavior. Imposing fees for urban freight transport might be a good strategy on its own, and it could also lead to a shifting of traffic density in other periods. This “off-peak delivery” approach is intended to reduce congestion and improve logistics productivity, and has been successfully implemented in some cities such as New York City and London (Trunick 2004). Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe came into force on 11 June 2008. This directive stipulates the allowance of the concentration of tailpipe emissions, e.g. particulate matter (PM), ozone, and CO (EC 2008). Additionally, the European Commission’s White Paper 2011 on transport (EC 2011) sets the target of eliminating conventionally-fueled cars in cities by 2050 in order to reduce carbon emissions in transport by 60%. As a result, city administrations need to enact these regulations on a local level. The pressure on cities has been increasing since NGOs started suing city authorities where allowed limits for emissions in urban areas have been exceeded.

Socio-political pressure is increasing in terms of green logistics and less congestion. It needs an adaptation of the regime as these can be limits to further growth based on the state of practice. However, to address these challenges would need a dramatic change in the state of practice, because the techno-organizational concept of cars and trucks by combustion engine, road usage, etc. enhance the pressure – vehicle by vehicle. The pressure is thus systematically produced from the core concept of car- and truck-based mobility. Let’s consider in the next section what the behavior and dynamics at the regime level are.

3.2. The evolutionary phase of the road-based logistics regime

By “road-based logistics regime” we mean: the manufacturers of automobiles (cars, light-duty vehicles, and trucks), providers of logistics services based on automobiles, the policy level trying to facilitate city logistics (and

general mobility) based on automobiles, the large-scale infrastructure and reconfiguration of cities towards automobiles needs, the users of logistics services (e.g. production methods like just-in-time, parcel deliveries), and science working on concepts for city logistics. Actors, rules, and behavior are aligned with the automobile's needs. However, they are under pressure as we have seen above.

Germany can be considered as a lead market in automobile production (von der Linde 2002). We thus use data from the German Automobile Association (VDA), the voice of the industry, to demonstrate the regime behavior.

In terms of the product innovation pattern of the automobile producers, the VDA data (2018) covering major innovation across 130 years of automobile history show a clear pattern in line with that of Christensen (1997a): Competition regarding functionality was focused on in the period 1875-1930, when the car was developed from a three-wheeled horseless carriage, without roof, lamp, power, or steering rod, into a modern automobile with all functionalities from today (according to Geels 2005, the Ford T was particularly ground-breaking). The next level of competition was on reliability, where performance (muscle cars), technical refinement of components (electronic injection e.g.), stainless and robust quality cars was the result until the 1990s. After European, Asian and American automobiles had achieved similar levels of quality (automation of production was a key driver here, see below), today companies compete fiercely regarding user convenience. This competition is mainly influenced by information and communication technologies (ICT) such as driver assistant systems, connectivity, and entertainment features. One might assume that this competition will culminate in automated driving, the highest stage of convenient automobiles. The particular case of heavy trucks is advanced in the stage of innovation competition: here all European OEMs were found guilty of forming a price-fixing cartel since 1998 (EC 2016). A cartel is the only opportunity for competing companies to avoid a price competition on homogenous goods. Thus, according to the theory, the last stage of the competition pattern is close to being entered. If the price competition is finished (Bertrand competition in the next years?) de facto further innovations will be impeded by the lack of margins for reinvestment.

How did the regime act on techno-economic pressure? The CTSE postulates that this pressure is highly attractive to be included in the incremental innovation pathway of the regime. In line with the reverse product cycle, ICT (as an external technology) was firstly applied in automotive to enhance efficiency (CAN bus system and automation of production lines / CIM) in the 80s, when the automotive Kondratieff cycle was in winter and the industry thus in a deep crisis (American and European producers in particular because Asian producers used ICT first for efficiency enhancements). Secondly, ICT was then applied to improve the quality of vehicles (active safety systems for reliability innovations; driver assistance systems (light, mirror, wipers, distant warning, parking etc.), touch screens, entertainment, and connectivity for convenience innovations). One level of new products in automotive enabled by ICT is the relatively young discourse on Mobility-as-a-Service concepts (MaaS). Manufacturers thus take, and will continue to take, the opportunities ICT affords them regarding efficiency, quality, and creating new products. The techno-economic developments become techno-economic pressure in terms of the landscape developments outlined above: The definition of an efficient transport system is changing. The answer of the manufacturers is automation to address the pressure.

The demand side in the regime (parcel services providers) has changed from a fulfillment system where the parcel had to be picked up at the post office by the customer. Efficiency was enhanced by introducing tour optimization software, fleet management software, barcode etc. ICT was then applied to enhance the quality of the service such as track-and-trace services, online processing, and information. Today, new products by parcel service providers include multiple delivery options for customer satisfaction, i.e. special and adaptive pick-up and drop locations, narrow time windows, and parcel boxes.

How did the regime act in response to the socio-political pressure? We evaluated the yearly reports of the VDA from 1961 to 2016 (VDA, several years) on statements and arguments concerning environmental issues. We found a clear pattern in line with Geel's triple embeddedness framework (2014):

1. Denial: arguments that the “problem is not existent”, “others are worse”, “alternatives do not appropriately contribute”, the “problem can be solved by policy” and so on were put forward until the 1990s.
2. Local search from ca. 1990-2010: arguments that “the industry has made a lot of effort, more than others”, “high investment have been made to solve the problems”, “high contributions and achievements in the

traditional technology”, “incorporation of selected alternatives”, “trials with alternatives but not as sufficient than traditional technologies” could be found in response to environmental issues.

3. Distant search starting from ca. 2010: triggered, for example, by government promotion of electric mobility arguments, “we are trying alternatives”, “proposals for alternatives”, “assessment of alternatives”, “achievements and potentials of traditional technology pathway”, “announcement of the enlargement of the product portfolio” are published in the reports.
4. Path re-creation: a clear commitment to green mobility in its full extent is still outstanding – in fact there are no signs of that.

Distant search can also be observed on the user side in the regime. The electrification of light-duty vehicles is the major pathway for this: DHL became an electric car manufacturer and UPS started to experiment with hydrogen trucks in their logistics fulfillment. However, let us assume electric vehicles are fully deployed. The limitations of the road infrastructure within urban areas persists. Logistics service providers thus experiment with new solutions such as drones, cargo bikes, mobilizing pick-up stations, high-speed tubes (see dynamics in niches). According to Geels and Schot (2007), the regime starts to tackle the challenge without any capable available alternative – a process of destabilization begins. Out of this process emerges the so-called innovator's dilemma, characterized by two main aspects: a) intensifying the optimization of established technologies (vehicle technology, delivery concept, and business models) towards an over-engineering of the system and b) an active exclusion of alternative technologies, as they threaten the established technology path and patents, market power, and profit margins (in latent market equilibrium).

Summing up, four major findings can be stated so far: firstly, the landscaped exerts remarkable pressure to modify the regime's innovation pathway. Secondly, the techno-economic pressure is included into the incremental innovation pathway of the industry regime; however, what is maybe not sufficiently addressed is the impact of the pressure on transport demand (new user behavior, requirement, consumption pattern etc.). Socio-economic pressure is poorly incorporated in the innovation pathway. Thirdly, the regime opens up (latent instability) to cope with the pressure; signs of a limitation of future growth by established practices are thus visible. Fourthly, past growth of the regime opened a systematic niche which regime players can barely fulfil, with time-space constraints on the ground restricting growing requirements for emission-free on-demand transport. Let us consider next the dynamic in niches where efforts can be observed to fulfill this systematic niche.

3.3. The dynamics in niche markets

The niche level is framed by socio-political and techno-economic pressure which is not sufficiently addressed by the dominant regime. A niche market is characterized by supply and demand beyond the mass market. That means it is subject to other functional requirements and asks thus to be served by alternative technologies. Applying this to the courier, express, and parcel (CEP) market means the established services are the mass market; the niche market is on-demand, emission-free, and instant parcel services. There is a higher willingness to pay for these services and functionality in contrast to established parcel services, where customers expect quasi-neutral costs.

The CEP market has seen double-digit growth every year for the last decade (BIEK 2018). This is unique: other segments in the logistic markets, such as contract logistics, general truckload, less than truckload, or bulk logistics, are mostly saturated with low achievable margins (Schwemmer 2017). The growth of the CEP segment has been triggered by e-commerce and new requirements (i.e. on-demand, instant, and flexible delivery services). The report Top 100 in European Transport and Logistics Services, published by the German Logistics Association (BVL), raises the question: “*Are there natural limitations for even faster delivery times?*” (Schwemmer 2017). It gives the following answer:

“[A] natural limitation for this development has not yet shown up, even with more goods getting enabled for e-commerce (e.g. fresh food) and new businesses which are focusing on the last mile concepts. For the moment, the rise of the number of B2C consignments and even higher demand of customers to be reached properly by their orders needs to be considered by decision-makers.” (Schwemmer 2017, p. 9).

CEP service providers have established smart, efficient, and powerful logistics service networks. However, some of their biggest customers (namely online retailers like Amazon, Alibaba etc.) have started to find their own solutions - mainly for the last mile. The online market is defined by intense competition between online retailers battling for customers and market shares. Apart from price and quality, retailers woo their potential customers by offering multiple delivery options. On-time delivery, choice of handover locations and person on the day of delivery, same-day delivery climaxing in instant deliveries within 60 minutes are new requirements for CEP service providers (Allen et al. 2017). The drivers for on-demand delivery options are inherent and strong.

Encountering the pressure from the regime and tackling the described requirements, the CEP market is compelled to find innovative solutions and feasible concepts able to fulfill on-demand services. However, it is hard for established logistics (network, vehicles, and organizational concepts) to provide these services. They require new functionalities and experimentation with new opportunities. Several concepts are being developed by small and large market players:

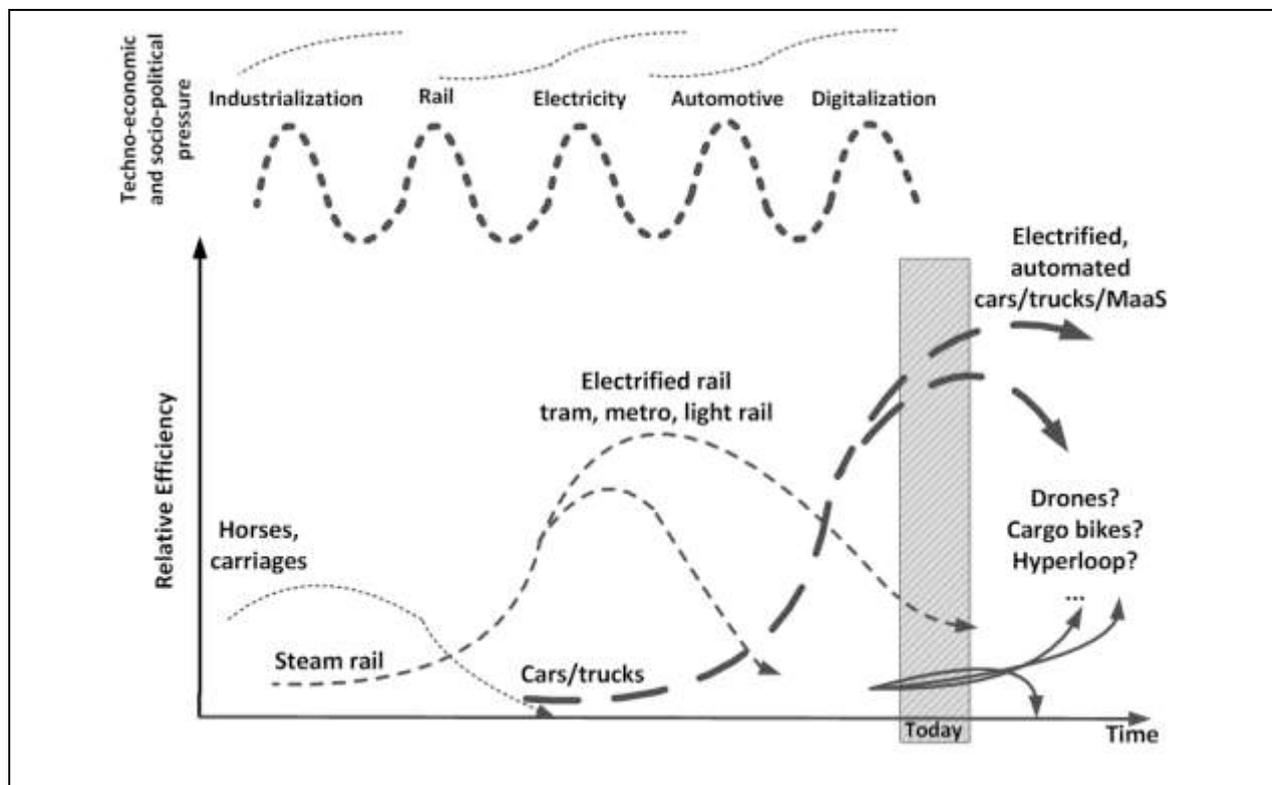
- Electrically assisted cargo cycles for last-mile deliveries in combination with urban (micro) consolidation centers and/or parcel lockers
- Delivery drones and unmanned ground vehicles for parcel delivery services,
- Airships as flying warehouses
- Tube systems (Hyperloop) with small compartments or single palette transport capacity.

Many major cities in Europe and also in Japan are piloting projects running cargo cycles with micro consolidation centers. In North America, Amazon, Alphabet, and DroneDeliveryCanada have been experimenting with drones to enable new distribution options/business cases. 7Eleven carried out a commercial drone delivery in the US in July 2017 while Amazon received a lot of media attention in 2017 filing patents on a new distribution concept with an airship as a flying warehouse in combination with drones as last mile distributors. More mature and integrated projects have been reported from China, where the online retailer JD.com – Alibaba’s main competitor – has implemented a network of delivery drones in a hub-and-spoke principle to satisfy online shopping demand. In Europe the concept of drone delivery is currently also in the experimental phase. The Parcelcopter of DHL gained a lot of media attention, while showcasing the feasibility of transporting medical goods to an island in the North Sea and postal deliveries to a small cottage in the alpine mountains. The Hyperloop concept has meanwhile been tested successfully on the technology level by several companies. It is designed to overcome long distances for on-demand services.

There is an upcoming dynamic on a niche level, with radical new technologies applied by non-conventional or new market players, all trying to find a techno-organizational configuration to serve the growing niche of on-demand e-commerce, emission-free and instant parcel services. While the established regime is in the growth phase with a mass technology on the mass market, a stabilization phase can thus be observed in a niche market with niche technologies.

We have discussed the status quo of the transport system by application of the CTSE. Figure 1 shows the systematics of the status quo by the CTSE on an aggregated level and a long-term perspective. We see in the figure that, by 1890, rail was the dominant transport system. The systemic niche of rail was that it was restricted to service on tracks. In conditions of growing urbanization, the space between tracks grew as cities became bigger. Electrification, tramways/underground/city light rail were the intensification of the rail regime pathway faced with the pressure of utilizing the opportunities of the electrification Kondratieff cycle at that time. Horses and horse driven carriages were the major opportunity for mobility apart from tracks. In fact, this was the limit for productivity and thus the niche was exploited by early cars and trucks. They first replaced horses and went on to push rail into a phase of degeneration. Today, having transformed the transport market, cars and trucks are the dominant forms of mobility. Under pressure, the regime is exploiting the opportunities of the current digitalization Kondratieff cycle through automation and MaaS, and is more or less moving towards electric mobility. However, they also have a systemic niche: On-demand instant mobility enabling higher speeds and thus a new level in time-space interaction. This new efficiency requirement can hardly be fulfilled on congested ground space even with electrified, automated mobility service vehicles. Moreover, consider that the pressure is most significant in metropolitan areas – where automation is a most difficult engineering/societal task. Thus, several disruptive new concepts are being worked on to elaborate and serve growing niche demand. One example is given for the parcel market.

Figure 1: Systematics of the evolution of transport systems in long term perspective



4. Why drones are not as much baloney as they seem to be today

In the analysis of the status quo of the transport system, we have seen systemic limits of growth for the established technology and practice. For the most part the literature does not deem these limits hard or inevitable, but takes the view that they can be tackled by further technical progress and/or technology transition management towards electrification and automation. Thus, from the mainstream point of view, any future where road transport is replaced, such as happened to inland navigation two hundred years ago and for rail and horse carriages one hundred years ago, appears highly unlikely. The key, however, is that all replaced modes and means had limits to the growth of efficiency for the consumers of transport (different economic sectors, private users). The replacing technology provided paramount new input factors for consumers, facilitating tremendous new levels of efficiency. Such efficiency gains are not unidimensional but comprise multilateral characteristics. In this sense, for example, rail naturally has a greater capability to transport masses than cars and trucks. However, this was not the point of future efficiency requirements or their limits. At that time the limits of efficiency were spatial availability and individuality of transport, which made cars and trucks superior to rail. Note, early cars, maybe by 1900, were not viewed as being technically capable of performing at the same level as or competing with rail. They could only “compete” in the systemic niche of rail: the space between tracks for individual mobility.

The starting point for the “assessment” of disruptive alternative concepts today is very similar. The current performance and size of drones, the needs of the urban delivery market, and the regulatory status quo only allow tests and trials for drone delivery. They are underperforming and hence cannot compete with trucks in the truck’s market and market rules. Regulators see threats and hazards such as mid-air collisions and ground risks (impact injuries or flight into terrain). With many recent drone delivery test cases in remote or rural areas, it is common sense that these risks increase markedly with the application of drone delivery in urban areas with congestion,

inhabitants, and obstacles. Ironically, this is the area with the highest demand and density of on-demand delivery from e-commerce: congested mega-cities whose growing populations have increasing disposable income and access to online retailing. Quality and speed of the delivery in last-mile services were identified as a key differentiator for e-commerce players' success in the marketplace by a McKinsey study in 2016. The study also found out that nearly 25 percent of today's consumers were willing to pay significant premiums for the privilege of same-day or instant delivery. The study expects this share to increase, because this trend is even more visible with younger consumers. The niche exists, the main question resulting is: who can serve it best, and with what technology? Looking to the case of drones in urban last-mile logistics, currently there is no larger-scale drone network of delivery drones in place worldwide. Nevertheless, there are already some studies and research results available.

A study from 2018 published by the International Transport Forum of the OECD looked into innovative use-cases for drones. It stated that "the main policy concerns regarding freight drones, beyond the safety and security of vehicles and airspace management system, energy consumption per ton of freight delivered, related emissions and the impact on the workforce. Depending on the location and scale of operation other environmental impacts, including noise, visual amenity and the effects on land use values also need to be taken into consideration." (OECD 2018) Another study by Stolaroff et al. (2018) concluded that package delivery by small drones could reduce greenhouse gas emissions and energy use in the freight sector. As the technology matures and the capabilities of drones increase, regulation becomes the most apparent hindrance for the application of drones in urban freight transport. A whitepaper of Stanford Business school identified several emerging trends in drone delivery, when not limited by factors such as citizen complaints about crowded and noisy skies, pedestrian accidents, and regulatory roadblocks. These trends include seller-driven delivery models, where sellers insource delivery using drones or intermediary-driven delivery models, in which a buyer visits a website and orders products that the intermediary then uses a drone to pick up from a seller.

Even with fast technological development in the drone-technology sector (propulsion, payload, endurance, stability), there are still some areas where data and experience are lacking. An economic assessment is very uncertain, due to lacking data on the total cost of ownership. It seems obvious that an unmanned platform with electric propulsion has significant advantages in operational costs against a manned ground vehicle with fuel and labor costs. To become a real alternative, long-term tests need to establish experience with urban drone delivery, to address factors such as weather, theft, and malfunctions, not forgetting questions of acceptance and insurance. Pressure to speed up the integration of urban drone delivery can come from the economic field, where increasing demand promises high profitability and market share. However, delivery drones are specifically designed to serve the niche market of on-demand instant deliveries. The assessment of the drone-concept and characteristics is that it is not yet an economically and technologically competitive alternative to traditional distribution concepts in the last-mile-delivery mass market. Today, the deployment of drones seems to be limited to special use-cases in inspection and surveying, agriculture, and some other smaller niches. However, each application field of drones expands the young regime's experience. It moreover reveals how this new technology improves the efficiency of other sectors compared to established technologies and practices.

The major point here, in the disruption of the base of competition, is the interrelation of the innovator's dilemma and the attacker's advantage of competing technologies (the interdependency between stabilization and growth phases, see the CTSE). Actors in the innovator's dilemma overestimate the potential of development of an incremental pathway and tend to over-engineer the system for exploiting potential further efficiency improvements (the quotation of the logistics industry regarding "*natural limitations for even faster delivery times*" given above is an example). Actors working on disruptive alternatives, however, are at the very beginning of any techno-organizational development and thus still underperforming. But it is inherent that marginal improvements for an underperforming system are quite a lot higher than for a system optimized throughout if there is not a contradicting physical law or suchlike. We do not say that no further improvements are possible for road-based logistics, for instance; of course they are, but we do say that future improvements will be costlier with smaller improvements – with this tendency only increasing. However, in congested and restricted areas, the niche of on-demand deliveries needs other techno-organizational functionalities and can hence poorly be served by the established delivery system with light-duty vehicles – even with higher capital input.

Currently, the drone seems to be in the stabilization phase (1), in which suppliers experiment in market niches. The attacker's advantage of drones would be that they currently work in niches (on-demand instant delivery is one,

passenger transport in Dubai another) where their functionality is superior to established dominant technologies and practices. This makes their underperformance in traditional functionalities irrelevant for niche technology users. Moreover, if the market for drone's deployment continues to grow, these conditions make it highly attractive for capital input. This would enable a mechanism of innovations with high marginal improvements. Drones can be a great deployment field for automated, electric mobility technology. The drone is basically designed to be autonomous. Moreover, many challenges in automating ground transportation do not exist for drones. Thus, a knowledge transfer from the automation technology sector to airborne drones is a further argument that the attacker's advantage is possible for drones. Another highly beneficial aspect of airborne transportation is efficient transport using a line of sight connection, "as the crow flies", providing a tremendous upgrade of infrastructure capacity available in three dimensions. Furthermore, no spending on supporting infrastructure en-route is needed. Roads and rail tracks have to be maintained and every new build and more efficient connection between two points needs significant investment. For airborne delivery there is just the need for loading, departure, reception, and unloading. The social efficiency gain is tremendous compared to building and maintaining roads, tracks, and channels in the past and future. It can, however, be expected that the rise of urban drone delivery or passenger usage of drones will have an impact on how buildings are planned and perceived. But this was also the case for cars, with either roads or city structures being prepared for cars' needs – this issue was then addressed by growing demand for road-based mobility (car-friendly cities).

Thus, in technological and organizational terms, the airborne drone would represent a new quality level for e-commerce traders and their distribution channels. The core question is whether the future growth of e-commerce demand will concentrate on flexible, speedy deliveries and similar application fields like air taxis in the metropolis. The activity of e-commerce traders supports future elaboration of demand. Moreover, the improvements require an injection of capital, in terms of both knowledge and money. A further concentration of capital will be likely if demand for e-commerce and, in particular, flexible and speedy deliveries continues to grow. Then a fast and low-risk return on investment is likely, which attracts venture capital and engineering knowledge for innovations. However, the same is true for other technologies competing in the niche markets with drones, such as Hyperloop. In this sense, drones are "just" high potential because they explicitly address niche functionalities, adopting infrastructure knowledge advantages from autonomous and electric engineering, and being able to be used in many deployment areas. They thus represent a potentially disruptive efficiency gain for social and economic development.

5. Conclusive discussion of the findings and policy implications

By 1900, railways were the dominant transport mode. It was the mode for long-distance travel, suburban travel and, in the form of tramways, for urban transport – highly efficient through electric drive trains, its wheel-rail system, and coherent networks. For final distribution and accessibility, horse-driven carriages and modern bicycles were used as transport modes. For a long time, actors in the dominant rail regime were of the belief that the upcoming horseless carriages (later labeled as automobiles) were only capable of replacing horse carriages, and automobiles were thus not their concern. However, history shows that the replacement of horses and horse carriages in urban mobility was the only niche where automobiles could grow. Note: this niche could not be served by rail since its network has never been and is unlikely to be this dense. The potential of the automobile to increase individual and flexible mobility, as well as the growing demand to reach locations beyond the railway tracks, was systematically underestimated by the railway regime. That characterizes the attacker's advantage of automobiles and made the dominant regime fail.

Currently, it is ICT that drives changes in society and the economy. The success of e-commerce just expresses the power of platform economics, new companies and distribution channels, and user behavior and expectations. Thus, it is less a question of "Will it continue?", but more the question of "When will the established physical transport be unable to serve demand efficiently and fast enough with respect to consumer's expectations?" Furthermore, the question arises "Which solution fits market requirements best?" The future is not at all limited to drones only! What we have elucidated in this paper is that it is likely that established regimes are faced with considerable limits to further growth. These limits are systematically produced by the established technologies and

practices (traffic challenges, environmental challenges, and economic challenges). What we have further illustrated is that drones have great potential to overcome the aforementioned challenges and provide a promising technology for future growth resulting from the on-demand economy. Even other deployment areas such as passenger transport, monitoring, and in agriculture can be served by providing a new base of productivity input.

Public and private actors are looking for solutions to future mobility and lead markets (often misleadingly labeled as sustainable transport). Disruptive innovations are most promising for future economic growth in drastically changing the base of competition. Thus, our main concern for policymakers (and other interest groups) is that they consider disruptive solutions as part of the search. The situation today has similar characteristics to 1900. Due to the dynamics of that time nobody knew which regime would be established in the future: electrified tramways and railways (intensified regime innovation pathway), electric, combustion engine or gas driven horseless carriages, motor bicycles, or bicycles, etc. Today we know the end of the story. But what would we have recommended to policymakers, if we travelled into the past? We would probably have recommended promoting the car, i.e. to work on social acceptance, to provide test fields where technology could be demonstrated, and to intensify R&D for technical refinement, aiming to achieve a good position in global competition in the market of the future (lead market). Even if the technology had a capability of only 10 horse power, two cylinders, was technically not at all robust, with full rubber wheels, largely still without a roof, lighting, etc. All these measures are taken today for cars and trucks, as they were for the railway in 1900.

Thus, today, it is worth considering policy tools for the promotion of disruptive solutions. In the game for future markets, drones possess high potential, but others may, too. We are convinced that public funding should be invested in a technology-open competition on future mobility forms. To open and promote the competition for future mobility between old, refined, and disruptive solutions while not rejecting one or pre-judging another is the key message of this paper. The more open the competition is, the better the results for market needs will be. In this way, public resources and subsidies are invested most intelligently.

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