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The future of urban freight transport: A data-driven consolidation approach to accompany cities on their path to zero redundancy in freight movement

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Abstract

Urban freight transport is characterized by an increasing number and frequency of uncoordinated freight delivery trips into the urban space. For municipal decision makers, this is particularly challenging in geographic regions with high population density and corresponding freight demands, which, when processed inefficiently, can lead to an excessive utilization of urban space. This paper lays the fundament to enable municipal decision makers with a data-driven, holistic perspective on urban freight transport by consolidating related information inside a management cockpit. We apply a scenario-based approach to develop the software framework for the cockpit, which serves as a supportive system for the municipal decision-making (e.g., by identifying inefficiencies inside the urban freight transport system). Finally, we show the feasibility and potential benefits of our approach by implementing a city-managed urban consolidation center using integrated data for the calculation of the systemic benefits compared to a pre-defined base scenario.

Keywords:

Urban Freight Transport, Municipal Decision-Making, Data-Driven Decision Support

Introduction

Today, around 55% of the world's population lives in urban areas – a share, that is expected to increase up to 68% in the course of the following three decades (United Nations 2018). Among others, urban areas provide an accumulation of goods (e.g., shops, supermarkets) and services (e.g., schools, universities, various leisure time activities) which leads to various demands with regard to urban spaces. Given a limited supply-side, this subsequently results in a competition for urban spaces and their usage.

One share of the urban spaces is demanded by the mobility of goods in the course of urban freight transport (UFT) activities. Due to an increasing frequency of freight deliveries with comparatively low utilisation rates of assigned delivery vehicles and a higher number of UFT trips (Letnik et al. 2018), municipal decision makers are more than ever challenged to improve the liveability and enjoyability of the city for residents and visitors, while, at the same time, minimizing the negative effects on the resulting traffic volume (e.g., congestion, emission of noise and pollutants) (Brůhová Foltýnová et al. 2018).

The above-mentioned combination of an increasing number of freight deliveries and trips with comparatively low utilisation rates of the assigned delivery vehicles leads to an unnecessarily high usage of the urban transportation infrastructure (e.g., capacity consumption, congestion) as well as excessive energy-consumption and emissions with regard to related vehicle movements. This constellation is particularly critical in geographical regions with a comparatively high population density and thus an accordingly increased transport demand density. For these regions, there is a particular need for action by municipal decision-makers to minimize the overall consumption of urban space and at the same time regulate this consumption in such a way that it only affects the urban transportation network during the actual period of demand.

Recently, the World Economic Forum has published a study on the future of the last-mile delivery ecosystem. Driven by the above-mentioned combination as well as emerging technologies and market participants in the field of UFT, one key aim of the study has been to deliver an input for strategy discussions of last-mile ecosystem related players (e.g., to encourage partnerships or to accelerate the development and implementation of effective interventions). One central outcome of the study is a forecast for the development in last-mile delivery for the "global top 100 cities" until 2030. For the scenario, in which no interventions will be undertaken in the course of the upcoming decade, the authors predict that the number of delivery vehicles would increase by 36% and, related to their movement, an increase of emissions (by 32%) as well as congestion (by 21%) could also be expected. (World Economic Forum 2020)

The above-mentioned forecasts underline the raison d'être of worldwide objectives regarding the sustainable development of the planet such as, for instance, the United Nation's *Sustainable Development Goals* (e.g., aiming at ensuring a sustainable development of the planet on economic, social as well as ecologic level (United Nations 2015)). On a continental level, for instance in Europe, these goals are being taken up through the development of supranational initiatives, such as the European Commission's *HORIZON 2020 Smart, Green and Integrated Transport* (e.g., aiming at resource efficient transport or developing new concepts of freight transport and logistics (European Commission 2019)) or the *White Paper in Transport* (e.g., aiming at CO_2-free city logistics in urban centres by 2030 (European Commission 2011)). Furthermore, the forecasts indicate an immediate need for action through the various actors in UFT.

From a data-driven perspective, urban freight deliveries can be described with the help of various parameters. Among others, these are the *origin, current position, destination* or *route* of a delivery as well as further properties related to the delivery (e.g., *shipper, receiver, volume, weight*) or the delivery vehicle itself (e.g., *type, dimensions, emissions*). Based on existing interrelations between these parameters, performance indicators can be deduced from multiple perspectives (e.g., per vehicle, per fleet, per city segment) and conclusions regarding the capacity as well as the performance of the overall urban transportation network can be drawn. Gathering the knowledge (e.g., current values, development over time, development per city segment) about these parameters as well as their interrelations at a central point represents a promising approach in order to set the fundament for integrated data-based solutions (e.g., bundling of deliveries, dynamic routing) for the continuous improvement of the productivity and efficiency of the overall urban transportation network.

Aiming at these systemic benefits, Otte et al. (2020) have discussed a data-driven approach for shifting the cities role in UFT from observation to operative steering by gathering information from various actors at a central point as a fundament for municipal decision-making from the perspective of the overall system (cf. chapter *Related Work*). One key outcome of their work is an overview of the involved data related to deliveries, delivery vehicles and the overall transportation network as well as a proposal for performance indicators that could be used by municipal decision makers in order to steer the freight transport into, within and out of the urban area.

In this paper, we build up on this concept by contributing to enable municipal decision makers to take a holistic, data-driven perspective on UFT:

- We develop the fundament for a decision support system for municipal decision makers in the form of an UFT management cockpit. In particular, we explain the applied scenario-based approach and describe the software framework, the associated data processing pipeline as well as the related decision-making process. We show the feasibility of this approach by implementing and evaluating one particular scenario for the City of Aachen: a city-managed urban consolidation center (cf. chapter *UFT Management Cockpit for Municipal Decision Makers*).

Through this approach, we create the possibility to identify inefficiencies within the system from an overall system-wide perspective and thus provide a fundament for future decisions and actions of municipal decision makers on their path to zero-redundancies in urban freight transport.

Related Work

In order to prepare municipal decision makers for the operative steering of UFT systems, bringing the available, related data together at one central information infrastructure poses a central requirement. In this chapter, we therefore present the most recent preliminary work on this concept from an information technology perspective.

In the course of the last two decades, the research field of UFT as well as related sub-topics have been subject to scientific discussions from various perspectives. In their recent work, Otte et al. (2020) have presented a new perspective on this field. Driven by national and supranational objectives regarding the sustainable development from the perspective of Germany respectively Europe, the authors developed a data foundation for the centralized, operative steering of the UFT system through municipal decision makers. Starting with a collection of the existing variety of terms for *urban freight transport* (e.g., urban freight logistics, urban freight distribution, urban goods distribution, urban goods movement, urban logistics, city logistics) as well as the related subtopics inside this research field, they take a control system perspective on the UFT system from the view of municipal decision makers.

In their approach, the system consists of *nodes* (e.g., intersections), *edges* (e.g., streets) and *entities* (e.g., shipments, vehicles) inside pre-defined *system boundaries* (e.g., city boundary). It experiences *inputs* (e.g., transport demand for people and freight) as well as *influence parameters* (e.g., weather conditions, events) and generates *outputs* (e.g., traffic flow, vehicle load factors, cost-benefit relations) as well as *systemic losses* (e.g., congestion, emissions of noise and pollutants). The outputs are in the form of measurements, calculations (e.g., impact-analysis), or estimations (e.g., predictions).

One central aspect behind their data-driven approach is the systemic relationship between shipments, vehicles and the urban transportation network as depicted in Figure 1.

Figure 1 – Systemic relationship between shipments, vehicles and the urban transportation network (Otte et al. 2020)

The collection of related data is one essential step in the approach of Otte et al. – for each of the elements from Figure 1, they collect data and describe their interrelations as well as suitable data sources. From their perspective, the elements can be described with the help of the following parameters:

- *shipments* (e.g., origin and destination; dimension; volume; weight; shipper; job number; shipment type; receiver type; quantity)
- *vehicles* (e.g., freight carrier; type; dimension; position, destination and route; load capacity; load factor; emissions; quantity)
- *transportation network* (e.g., street segment length and capacity; intersections; hub location, capacity and load factor; extent of individual and public transport)

They identify the following three categories of data sources to obtain the associated data: *measurements by the city* (e.g., sensors to count vehicle movement), *data generated by other actors in urban freight transport* (e.g., planned deliveries and load factors from freight carriers), and *data from other sources* related to the urban transportation network (e.g., event calendars for peak forecasting).

Based on this collection of delivery-related data and the existing systemic relationship between the involved data, Otte et al. suggest suitable performance indicators from the perspective of municipal decision makers (e.g., planned and processed shipments; shipment flow; vehicle load factors; share of freight traffic). As the region of interest might differ from single street segments over districts up to the overall transportation network, they also suggest different reference values for each performance indicator accordingly, such as *per street segment / district* (spatial*), per time frame* (temporal) or *per freight carrier / vehicle.* Through these measurements and calculations, municipal decision makers can assess the current situation of the UFT system, observe its time-dependent development, deduce action needs and evaluate the impact of undertaken actions as well as existing influence factors in a fact-based manner. (Otte et al. 2020)

UFT Management Cockpit for Municipal Decision Makers

This chapter aims to develop a data-based decision support system for municipal decision makers in the form of an urban freight tansport management cockpit. In the course of the chapter, we explain the scenario-based approach behind our work and describe the software framework, the associated data processing pipeline as well as the related decision-making process. Finally, we show the feasability of our approach by implementing one particular scenario in order to deduce an exemplary fact base for the subsequent municipal decision-making through a comparison of the outcomes with a pre-defined base scenario.

Scenario-based approach

As a starting point for our approach, we take an *ideal scenario* in which all the information are available to the municipal decision maker at the time of decision and in the quality needed (e.g., information about all the planned deliveries into the city center). Given this starting point, a broad action space can be imagined in order to steer the freight transport in a city-friendly manner, such as filtering (e.g., influx regulation depending on vehicle type or load factor) or (re-)routing vehicles (e.g., direct routing of vehicles with low emissions and high load factors into the city center through priority streets).

As we assess the (re-)routing of vehicles as more likely to be realizable without conflicting with existing legislations (e.g., discrimination-free policy making) and as VRP solutions are well-established approaches in research and application (cf. Lagorio et al. 2016), we examine this as an initial scenario for the management cockpit. Aiming at a maximum efficiency with regard to the deployed delivery vehicles inside the urban transportation network, we combine the VRP solutions (for further readings, cf. for example Awad und Elshaer 2020 or Braekers et al. 2016) with an urban consolidation approach (for further readings, cf. for example Björklund und Johansson 2018).

By selecting this combination as an initial use-case, in which the city takes over the responsibility to consolidate all the inbound traffic (e.g., including the choice of delivery vehicle, assigned shipments and routes) in one center in order to plan the entire deliveries based on this extended, consolidated data fundament, we also choose an approach, of which the exploited benefits for the overall transportation network can be shown in a fact-based and intuitive manner.

Software framework

Figure 2 presents the data processing pipeline for an UFT management cockpit for municipal decision makers and indicates the decision-making process as well as the associated feedback loop into the cockpit.

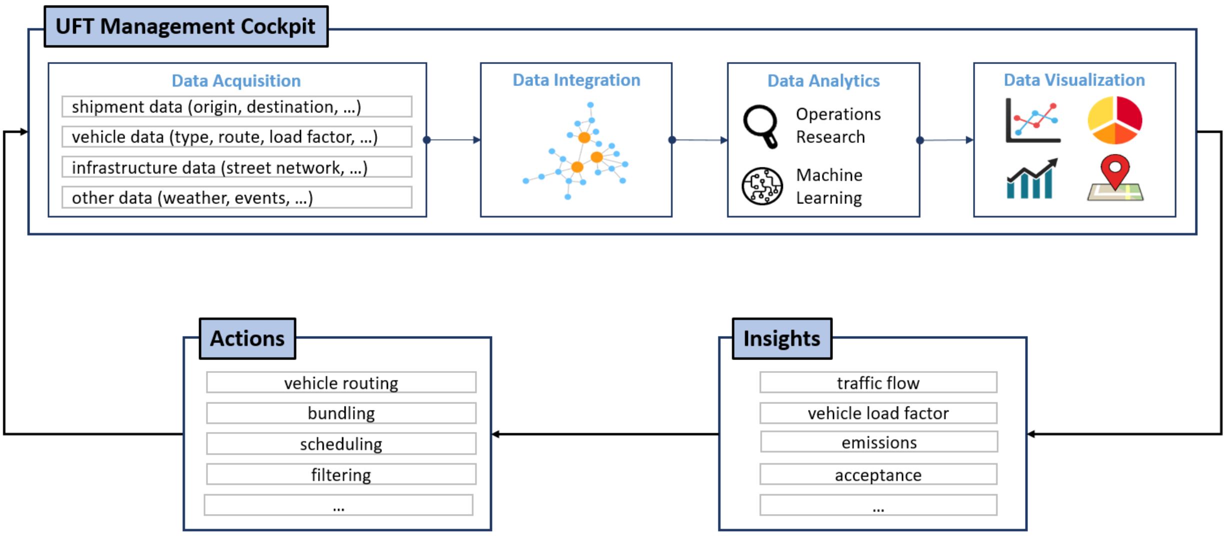

Figure 2 – Data analytics pipeline and decision-making process for the UFT management cockpit

The data processing pipeline consists of four steps: *data acquisition* (e.g., shipment data, vehicle data, infrastructure data), *data integration, data analytics* (e.g., with statistical methods, machine learning) and *data visualization*. The results of these data processing steps enable the deduction of insights into the performance of the UFT system and serve as a fundament for the decision support respectively the deduction of targeted actions by municipal decision makers.

Exemplary scenario: city-managed urban consolidation center

Description

Geographically, we decided for the City of Aachen as a first exemplary use case, in which five different service providers act independently from each other within the same freight delivery market. The locations of the involved orders are generated randomly within the urban area of the city.

As depicted in Figure 3, each of the service providers operates a freight depot at a randomly selected location within its corresponding bounding box in the periphery of the city (cf. Figure 3 – A, B, C, D, E). The city-managed consolidation centre is positioned at a random location in the orange bounding box, which has been thoughtfully positioned in a sub-urban area close to a nearby highway intersection (namely A4, A44, A544) in order to increase its accessibility for long-distance traffic.

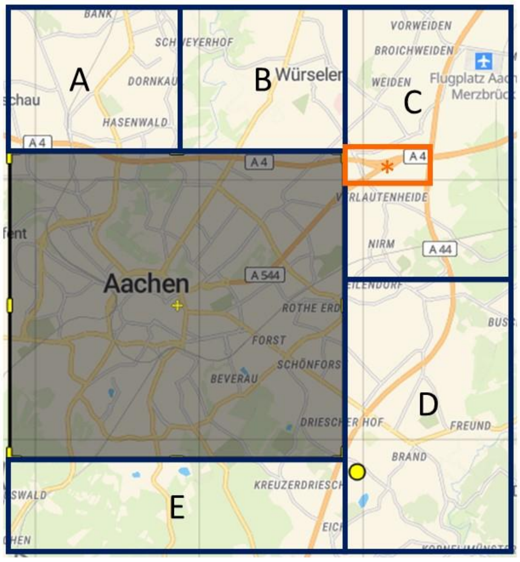

Figure 3 – Periphery of Aachen including bounding boxes for the locations of the freight depots (A – E; orange box for city-managed consolidation center)

Implementation

For the technical implementation, we decided for a python-based software stack using existing libraries in order to realize the desired functionalities. In particular, these are *flask* as a fundament for the web development, *OSMnx* to build the street network from Open Street Maps, *folium* to visualize map data and Google OR Tools to solve the VRPs.

Simulation and Results

Initially, the user defines the overall environment parameters (esp. *velocity* of the involved agents to deduce time savings from distance savings) and the scenario parameters for each of the service providers – these are the *number of orders*, the *number of vehicles*, as well as the *load capacity per vehicle.* Once all the simulation inputs are given, the user can run the simulation and observe the progress of the different simulation steps running in the background in the log area (cf. Figure 4). For each of the selected service providers, a VRP is defined based on the given inputs as well as the corresponding locations of the depot and the orders. The VRP solutions represent an assignment of vehicles to orders without exceeding the defined vehicle capacities. Each assignment describes a route from the depot to the orders in an optimal order of delivery and then back to the depot. The optimization objective is the total travelled distance by all vehicles.

In Figure 4, we present the results of these calculations inside the prototype of the UFT management cockpit. The view is divided into three segments: a *configuration* segment on the left side (esp. definition of input parameters for the simulation), a *map* segment in the center and an *analytics* segment on the right side. Each of the segments presents an exemplary choice of information that can be adapted or expanded based on the examined scenario and the associated requirements.

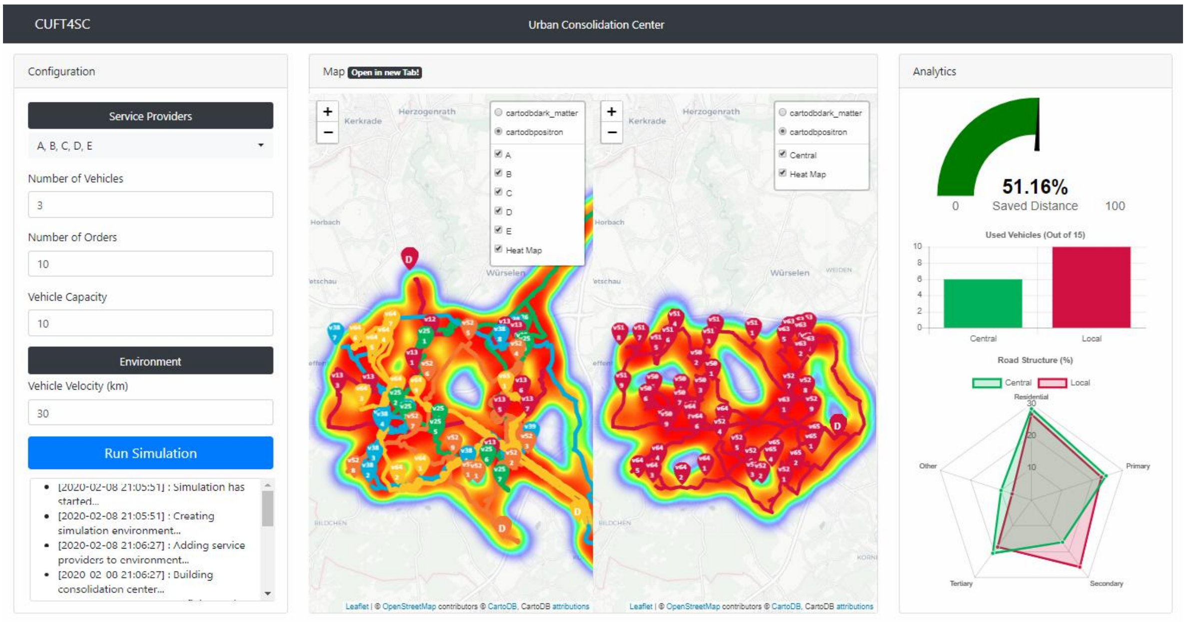

Figure 4 – Depiction of results inside the management cockpit

The *map* segment depicts the routes per vehicle and per service provider (indicated through different colors) on the left side respectively the routes per vehicle after consolidation on the right side. This enables a direct, visual comparison of both scenarios. In order to visualize the subsequent infrastructure utilization, we added a heat map layer based on the frequency of vehicles passing a certain street segment.

The *analytics* segment visualizes selected performance indicators in order to easily gain insights into the current situation inside the UFT system as well as exploited benefits in comparison with the pre-defined base scenario. As exemplary insights into the benefits of our approach, we implemented the calculation of the total travelled distance for both scenarios and determined the ratio of saved distance through consolidation (here: approx. 51%). Furthermore, we visualize the number of utilized vehicles and the resulting saving potential for both scenarios in a bar chart (here: 6 vehicles after consolidation instead of 10 vehicles for independent operations) and indicate the expandability of the analyses by presenting a radar chart showing the distribution of the utilized road types as a further example.

Conclusion and Outlook

Recently, the World Economic Forum has published a study on the future of the last-mile delivery ecosystem. For the scenario, in which no interventions will be undertaken by the involved actors until 2030, the authors predict that the number of delivery vehicles in the *global top 100 cities* will increase by 36% - accompanied by an increase of movement-related emissions as well as congestion. Taking this into account, we think that the need for action through the involved actors, including municipal decision makers, will increase drastically in the upcoming years. In this context, we also expect that an expanded action space will arise for municipal decision makers, which will imply increasing responsibilities as well as increasing shaping potentials with regard to the productivity and efficiency of the urban transportation network. In order to fulfil this expanded role in a targeted way, data-driven decision support systems will be needed.

The vision behind our work is to enable municipal decision makers towards an efficient, operative steering of the UFT system including the proactive management of the potential negative side effects (e.g., congestion, emissions). As an essential step on this path, this paper aims at consolidating UFT-related information (e.g., from involved actors) in a decision support system in the form of an UFT management cockpit for municipal decision makers. One essential prerequisite for suchlike decision support systems is a sufficient data availability (e.g., quantity and quality) at the moment of decision, while an increased data availability allows the deduction of further insights with regard to the current situation of the UFT system as well as its performance. From our perspective, realizing a sufficient data availability is not only a matter of *technical aspects* (e.g., data access, data integration) but can also be, for instance, a matter of *legal* (e.g., data privacy, data ownership) or *organizational* aspects (e.g., existing processes or incentive systems for the data exchange) that should be considered in flanking research works.

The current implementation of the management cockpit is designed in an expandable (e.g., further scenarios), transferable (e.g., other geographic regions, for which the needed geographic information are available) as well as scalable way (e.g., larger data sets; further actors). Our future work will focus on the continuous expansion of the software framework with further scenarios while, at the same time, discussing their implications for as well as their interrelations with the UFT system. Further scenarios can be, for instance, varying delivery vehicle fleets (e.g., electric vehicles, cargo bikes) or priority-lanes for city-friendly delivery vehicles (e.g., high load factor, low emissions). In addition to these expansions, the initial simulative results should be validated by processing real-data (e.g., from public-private partnerships) and the presentation of the results should be enriched by further suitable visualization approaches in order to support both the insight-generating as well as the decision-making process.

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References

1. Awad, H.; Elshaer, R. (2020): A taxonomic review of metaheuristic algorithms for solving the vehicle routing problem and its variants. In: *Computers & Industrial Engineering* 140. DOI: 10.1016/j.cie.2019.106242.

2. Björklund, M.; Johansson, H. (2018): Urban consolidation centre – a literature review, categorisation, and a future research agenda. In: *Int Jnl Phys Dist & Log Manage* 48 (8), P. 745–764. DOI: 10.1108/IJPDLM-01-2017-0050.

3. Braekers, K.; Ramaekers, K.; van Nieuwenhuyse, I. (2016): The vehicle routing problem: State of the art classification and review. In: *Computers & Industrial Engineering* 99, P. 300–313. DOI: 10.1016/j.cie.2015.12.007.

4. Brůhová Foltýnová, H.; Attard, M.; Melo, S. (2018): Topical collection on the role of planning towards sustainable urban mobility. In: *European Transport Research Review : An Open Access Journal* 10 (2), P. 1–3. DOI: 10.1186/s12544-018-0310-z.

5. European Commission (2011): White Paper on Transport. Roadmap to a single European transport area - towards a competitive and resource-efficient transport system. European Commission.

6. European Commission (2019): HORIZON - Smart Green and Integrated Transport. Available online at https://ec.europa.eu/programmes/horizon2020/en/h2020-section/smart-green-and-integrated-transport, checked on 4/12/2019.

7. Lagorio, A.; Pinto, R.; Golini, R. (2016): Research in urban logistics. A systematic literature review. In: *International journal of physical distribution & logistics management : IJPD & LM* 46 (10), P. 908–931.

8. Letnik, T.; Marksel, M.; Luppino, G.; Bardi, A.; Božičnik, S. (2018): Review of policies and measures for sustainable and energy efficient urban transport. In: *Energy* 163, P. 245–257. DOI: 10.1016/j.energy.2018.08.096.

9. Otte, T.; Fenollar Solvay, A.; Meisen, T. (2020): The future of urban freight transport: Shifting the cities role from observation to operative steering. In: *Proceedings of 8th Transport Research Arena TRA 2020*. DOI: 10.18154/RWTH-2020-02971.

10. United Nations (2015): Transforming our world: the 2030 Agenda for Sustainable Development. Sustainable Development Goals (SDG). Ed. United Nations, checked on 2/8/2019.

11. United Nations (2018): 68% of the world population projected to live in urban areas by 2050, says UN. Available online at https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html, checked on 1/23/2020.

12. World Economic Forum (2020): The Future of the Last-Mile Ecosystem. Transition Roadmaps for Public- and Private-Sector Players.