Lessons from the Regulation of E-scooters through the MDS Standard: Policy Lessons for Connected Vehicles

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Abstract

Connected vehicles generate new data streams that present promising opportunities for policymakers to monitor and learn from events and behavior. To explore what we can learn from how public entities leverage ubiquitous data streams for policy development and enforcement, we draw on a case study of the standard Mobility Data Specification (MDS) and its use by cities to regulate E-scooter operators. Our findings suggest that (1) the richness of real-time data changes the speed of policy revision, (2) data access enables moving some micro-decisions to the edge, and (3) policy will be formulated as fixed or flexible with different amendment rules.

Keywords: Policy Learning, Mobility Data Specification, Edge Policy Formulation, Data-driven policy, E-Scooter Governance

1. Introduction

Cities create and manage public resources (e.g., roads, paths, parks, buildings, and waterways) for use by residents, commercial enterprises, and social groups. Management of this economic and natural capital requires the development of policy that balances the needs of all stakeholders. Once created, a policy must be monitored and enforced. Since policies are not static, public entities are engaged in continuous learning on how to develop and adapt them (Cairney, 2020). The expanding number of connected devices opens new possibilities for decision-makers to learn from the effects of policies by capturing data on actual behavior in (near) real-time.

A public resource, such as a road, can support many city services, such as individual transport, pickup, and delivery conveniences (e.g., trash and food delivery), as well as urban services (e.g., utility connections). When establishing policies for the use of roads, cities rely on vehicle counters, traffic surveys, and resident input for data, among other sources. These data rely on observation (e.g., manual vehicle counting, roadside sensors, and cameras), and the resulting data are typically incomplete and spotty. However, as connected vehicles become common, cities may instead gain access to data generated by vehicles containing all movements (ITF, 2022). By mining such large and ubiquitous datasets, cities can elicit timely and precise information for planning and enforcing their policies.

Electronic scooters are an early example of how policy for the use of public resources by private enterprises can be informed by the usage data these new urban services generate (Fearnley, 2020; Laa & Leth, 2020). A connected scooter can report details of its status, location, speed, and so forth every few seconds. Patterns of collective behavior provide policymakers with a level of information richness not previously feasible. As a result, individual behavior can be precisely monitored to ensure that policies are obeyed and readily enforced.

Connected vehicles will allow cities to use information systems to create more effective policies (Shi et al., 2017). E-scooters are thus an opportunity to learn what data are needed to generate information and in what forms to improve policy formulation and its enforcement. Furthermore, it is desirable to create standards for providing such data so cities can avail themselves of commercial software rather than having to develop in-house applications. To this end, this paper addresses the following questions:

What can we learn from how cities use currently available connected vehicle data for policy development and enforcement when data is ubiquitous?

What are the implications for data exchange standards for connected vehicles to support the provision of data for city policy formulation and enforcement?

This is the first known study of the use of standardized spatial-temporal data to govern e-scooter

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use. As such, the focus is on empirical analysis as a pre-cursor to a later theoretical contribution.

The remainder of this paper is structured as follows. We outline our theoretical perspective on policy formulation and compliance methods as they increasingly become intertwined with the digital realm. Next, we describe the methods and analytical procedures used before discussing the resulting case narrative. We end this paper by offering a set of testable propositions as a pre-theoretical contribution by describing important relationships between data and policy and thereby answering our research questions alongside the implications of this research.

2. Regulation and compliance through technology

Policy comprises an institution's system of principles, guiding decisions on the configuration of rules, distribution of decision rights for different categories of rules, and procedures for their timely amendment (King & Kraemer, 2019; Nabli & Nugent, 1989). The term policy is 'scale free' in the sense that as long as there exist positions of authority, policies exist in systems of varying size and at multiple levels (King & Kraemer, 2019). The phenomenon of interest here is the role and effects of digital technology on public policy (related to the use of public resources).

Drawing on institutional theory, we consider policy in terms of (1) rules and constraints, (2) governance of the relations among stakeholder groups, and (3) predictability of policies (Nabli & Nugent, 1989). First, through configurations of multiple rules and constraints, public policies institute "prescriptions, commonly known and used by participants, to order repetitive and interdependent relationships" (Ostrom, 1986, p. 5). These prescriptions specify 'the rules of the game' in terms of required, prohibited, or permitted actions. Second, rules and constraints target social relations and are either willfully obeyed or enforced. Compliance through acceptance or policing is, therefore, an important element of public policy. Third, predictability is essential since actors are more likely to comply with policies that are comprehendible and exhibit a degree of stability (Nabli & Nugent, 1989). Predictability enables actors to understand how policies should be interpreted and anticipate the future trajectory of rules and constraints. Predictability is also vital for trusting that other actors will also comply.

Policy learning–gaining knowledge to inform policy and policymaking– can occur at multiple levels (Cairney, 2020; Moyson et al., 2017). At the micro level, learning occurs among individuals and is a social sensemaking process involving both power and uncertainty (Heclo, 1974; Lipsky, 1980). At the meso level, organizations involved in policy setting can implement objectives and establish norms, and modify both of these in response to events (Argyris & Schön, 1995). At the macro, or system level, learning can occur within, or more often across, government units when they share each other's experiences (Moyson et al., 2017).

Across the micro, meso, and macro levels, actors gain new insights related to how a policy is ostensibly expressed in codified rules and norms, and performatively enacted in practice (Feldman & Pentland, 2003; Latour, 1984). Learning about the effects of policy can, for example, result in a change in how policy is formulated as expressed rules and constraints to balance the needs of different stakeholders or to increase predictability through clarification. However, a policy is also enacted and enforced in practice at multiple locations and by multiple officials in an institutional system. For example, the central function of public administration is to make decisions on the allocation of certain frequencies for telecommunication to operators, and they can also enforce rules through financial sanctions for non-compliance. Simultaneously, individual public administrators at the edges of institutional systems, for example, schools, police forces, or welfare departments, make decisions on how policies are enacted and enforced (Lipsky, 1980).

The rapidly increasing number of connected devices and associated innovation (digitalization driven by technologies such as IoT, AI/ML, 5-G, blockchain, smartphones, etc.) poses new learning challenges and opportunities for policy development and enforcement (Brunswicker et al., 2019; Janowski, 2015; Velsberg et al., 2020). On the one hand, digitalization increases the speed, scale, and scope of innovations generated by a heterogeneous and distributed set of actors, (Bharadwaj et al., 2013; Nambisan et al., 2017) challenging public entities to adapt their policymaking processes. Simultaneously, the rapid increase in the number of devices with sensors and capabilities for processing, transmitting, and displaying data enables new forms of policy learning (Janssen & van der Voort, 2016) when data quality is sufficient and appropriate analytical capabilities are available (Nam, 2020). The use of big data sets can benefit policy analysis by increasing accuracy, expanding stakeholder participation, and enabling proactive measures based on predictive analytics but also comes with risks related to privacy, misuse and bias, and increased inequity (Shi et al., 2017). These opportunities and challenges for policy development and enforcement, associated with increased digitalization in general and connected vehicles in particular, pose interesting research opportunities for the IS field.

3. Method

To address our research questions, we employed a single, revelatory case study (Yin, 2009). Our revelatory case was the Mobility Data Specification (MDS), and we chose this set of API specifications as the focal study object for two reasons. First, we chose to study MDS as this is, to the best of our knowledge, the first instance where cities receive a ubiquitous set of data, conveying all trips and other relevant status changes for a specific type of vehicle fleet. Second, given the wide adoption of MDS by cities, it provides the opportunity to investigate the use of MDS in various regulatory and political contexts, thus allowing for the identification of common relationships revealing the interplay of policy and ubiquitous data.

3.1. Data Collection

The primary method was semi-structured interviews (N=19), which were conducted with representatives of cities (and other related public sector organizations) currently using MDS to regulate and follow up compliance with e-scooter policies. The interviewed organizations (N=15) were located in the U.S. (N=8) and the EU (N=7). As some interviewee participation was contingent on assurances of anonymity and confidentiality, we do not disclose the cities interviewed in this study. The interview protocol included background questions on why MDS was chosen, what e-scooter policies existed in the jurisdiction and to what extent MDS was used to enforce these, wins and challenges from using ubiquitous data generated by vehicles, and how cities worked with policy development using MDS.

We relied on snowball sampling to select our interviewees (Patton, 2002). We thus entered the data collection phase using existing connections in the field and ended each interview by inquiring about additional potential interviewees (also being cities using MDS). All interviews were conducted via video conferencing systems and recorded, and we ended our data collection when little new information was emerging. The recorded material was transcribed verbatim.

In addition to these interviews, we also base our findings on e-scooter permits of the interviewed cities, relevant news articles, as well as the specifications and examples of MDS (Open Mobility Foundation, 2022).

3.2. Data Analysis

Building on Eisenhardt (1989) and Miles et al. (2020), we analyzed the empirical dataset in the following way:

1. As an initial step, the first author identified excerpts from the interview data pertaining to the dynamics between e-scooter data sharing policy formulation and enforcement. This analysis step drew on the *data condensation* (Miles et al., 2020) technique by assigning tentative codes to the material using atlas.ti software.
2. As a next step, we extracted a matrix containing the excerpts and preliminary codes for *data display* (Miles et al., 2020). Based on this matrix, and the literature presented in chapter 2, we first jointly identified common themes across interviewed cities. Here, we especially found the framework by Nabli and Nugent (1989) as a fruitful sensitizing device to make sense of our empirical data.
3. Based on these themes and to generalize our findings beyond the studied case, we developed a set of tentative propositions to convey common dynamics between data and policy. Here, our analysis was characterized by intense iteration between re-examining the matrix, extant research, and developing theoretical propositions (Eisenhardt, 1989). More specifically, we scrutinized established literature on policy learning and formulation and used the propositions to convey the implications for policymakers to have access to a ubiquitous dataset

4. Results

4.1. The emergence of MDS and digital policy regulation for e-scooters

Starting in 2017, technology startups operating at the nexus of current societal technology advancements (such as societal smartphone diffusion, GPS sensors, and electromobility) launched a new means of transport – the e-scooter. This innovation allows citizens to use their smartphones to locate and pick up a free-floating vehicle, travel to their destination, and drop off the vehicle at any convenient location. However, the rapid wide deployment by operators like Bolt, Spin, Lime and Bird paired with massive adoption by citizens resulted in substantial effects on the lived urban environment of many cities, as explained by one city representative:

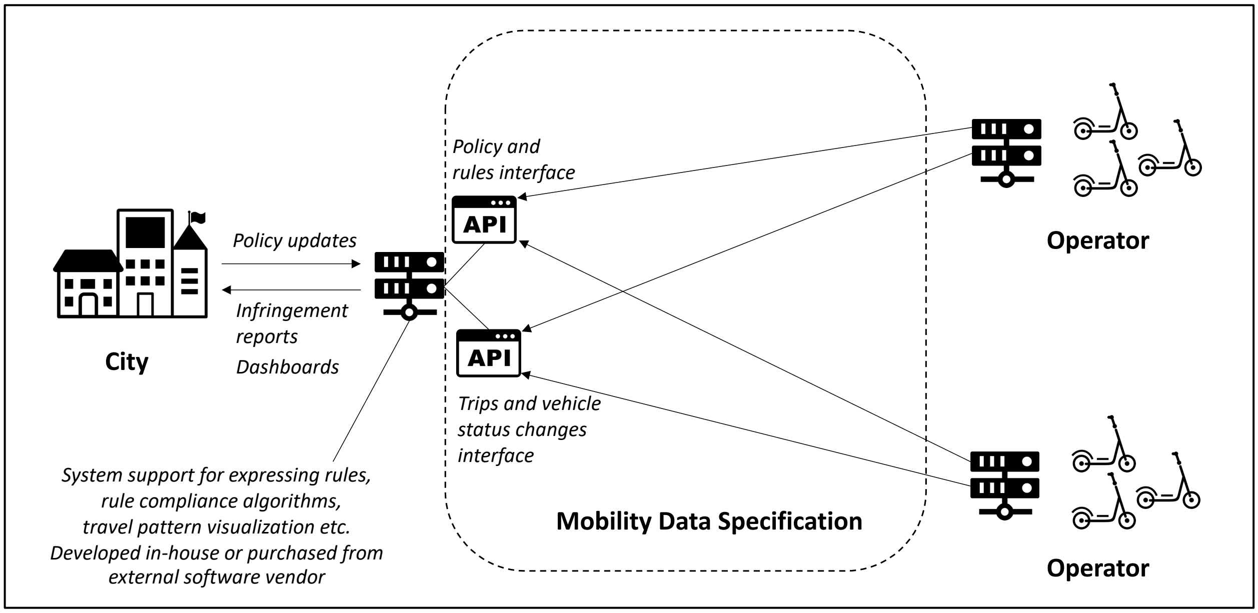

Figure 1- Overview of MDS in policy enforcement

Initially, it felt like it was almost like a real estate grab, and whichever companies that could pick up the most cities were the frontrunners and leaders in the industry. So that was a quick lesson for us to learn. Because after about two or three months of having our e-scooter pilot program up and running, scooters weren't being rebalanced or being fixed up, just being left pretty much throughout the city, so we had to put in an ordinance to [temporarily] no longer allow for scooters. City Mobility Program Manager 4 (US)

Cities and their citizens experienced issues with e-scooters, like decreased accessibility to streets, unsafe driving practices, and inadequate care of vehicles. Consequently, cities started developing and implementing new policies, targeting offending operators. Typically, these new policies materialized as *permits*, where operators' access was conditioned on meeting several criteria, as explained by a city official:

So there are local regulatory requirements, and truly it's a balance for commercial operators of how desirable your marketplace is versus meeting those requirements, and we use the right of the public right of way, which we regulate. Essentially, the vehicles are stored in the public right of way by a company between rides, and so that's why we're able to regulate it. City Mobility Program Manager 1 (US)

Since e-scooters are equipped with hardware like SIM cards, GPS sensors, controller software, and accelerometers, they can collect and act on digital information. Hence, by cross-fertilizing permit programs and the highly digitized vehicles' capabilities, many cities have come to include an obligation for operators to share data on vehicle movement and status, which cities use to measure rule compliance, among other things.

Los Angeles was one of the first cities to enforce such requirements, and in May 2018, it published a set of API specifications, the Mobility Data Specification (Zipper, 2019). These APIs specify how e-scooter operators should report historical trips and other relevant status changes (such as the extent to which a vehicle had been operated). The city of Los Angeles processes these data to assess whether operators are meeting their permit requirements.

Several interviewees stressed that this relatively proactive response emerged from recent experiences of digitally powered ride-hailing services (like Uber and Lyft). Many city officials considered these services to negatively impact the use of shared mobility solutions (like public transport) while increasing the stress on urban road networks. As a result, cities are now more attentive to emerging transportation modes and are better prepared to regulate emerging mobility services, as explained by a city representative:

A lot of where MDS was coming from was a reaction to wanting to better understand the impacts of e-scooters on our city streets. And on our accessibility and public right of way and public space and you know, wanting to understand that from the beginning, not waiting and trusting that we will get the data later. We knew that we wouldn't because we saw that with Uber and Lyft and the ride-hailing companies that they were just not willing to open up and share anything after the fact. Information Technology Specialist 1 (US)

In 2019, the ownership of MDS was transferred from the city of Los Angeles to the non-profit Open Mobility Foundation (OMF), and MDS has grown into a *de facto* standard for regulating e-scooters (see Figure 1for an overview). To manage digital e-scooter regulation, most of the interviewed cities have purchased software from commercial system integrators to implement policies, receive and visualize historical travel data, and monitor compliance. Buying from commercial system integrators is considered more cost-effective than developing systems in-house.

4.2. Rules and constraints

All interviewed cities stated that MDS is instrumental in managing e-scooter regulations connected to city permit programs. Many city representatives pointed to these permits as a valuable structure for rules, as permits do not have to specify the exact measures that operators need to meet, as explained by a city official responsible for an e-scooter program:

The outline of the permit says the Department of Transportation will provide equity requirements, but it doesn't spell out what they are. The Department of Transportation will set the data standards, but it doesn't say what they are in the law, so that we have that flexibility. But we did assure city council that we are going to implement these aspects. City Mobility Program Manager 2 (US)

Cities are not able to control e-scooter fleets directly but through regulations and compliance checks are made ex post any violations. All interviewed cities used MDS for rule compliance, and the majority of the interviewees also used MDS to formulate exact e-scooter regulations. Interviewed cities expressing rules digitally using MDS do so with the help of third-party software. Cities not using MDS rely on written ordinances or alternative digital formats. Those not using MDS were either using an older version, before capabilities to express rules digitally were introduced, or that the city had developed a system in-house to handle MDS and the rules remained to be implemented. The rules typically enforced through MDS are

- vehicle caps (i.e., the maximum number of allowed vehicles within a jurisdiction)
- geospatial driving restrictions (e.g., areas within a jurisdiction with specific speed limits, disallowed driving zones, and forbidden, as well as dedicated parking spaces)
- rebalancing scooter operations (e.g., removing scooters that have not been operating for a specified period, as this implies a malfunctioning vehicle)
- rules for vehicle distributions within a jurisdiction (i.e., that vehicles are available throughout an area, not just where they are most profitable)

To enable compliance with such rules, the operators share MDS data in near real-time. While implementation varies slightly, cities typically use these datasets for two regulatory measures.

First, the systems analyzing MDS data create a report (daily, weekly, bi-weekly, or monthly, depending on a city's preferences) summarizing, per operator, any potential infringements of current city regulations. Such violations typically include driving in prohibited areas or above speed limits, exceeding the maximum number of allowed scooters, not removing inactive scooters within a specified timeframe, or having scooters over concentrated in some city areas.

Second, the systems allowed city officials to probe operator data more thoroughly to assess whether current policies are followed or need adjustment. City officials use visualization tools to investigate scooter operations and figure out how current concerns could be improved, either proactively or as a response to a complaint. Throughout the interviews, there were numerous examples of how city officials made constant improvements to the digitalized rules to better meet the intention of the permits.

A recurrent example was how city officials were prompted to make minor adjustments to prohibit parking near business areas to avoid a sense of disorder. Other measures include road works in areas with many pedestrians. In these cases, cities might ban driving near road works to prohibit scooters from using sidewalks (to avoid excessive crowding). Also, adjustments are frequently made in response to time-boxed events. For instance, in the case of festivals, political demonstrations, or visits by high officials, cities use MDS to prevent vehicles from entering affected areas. City officials, in addition, continuously adjusted driving areas in response to actual practices.

In such cases, city officials might ban, or limit, driving on promenades and other recreational areas to maintain their walkability, or seal-off areas near the seaside to avoid scooters being thrown into the water. Officials also adjust allowed driving zones in response to security threats, such as disallowing driving on certain premises to avoid the use of scooters as getaway vehicles after criminal activities, or near protected zones like airports.

Practically, these more minor adjustments are made using MDS tools, whereby a city official creates a polygon on a digital map and assigns rules to the area. When a new rule is published, e-scooter operators are notified, and the rule becomes active. Before MDS, many cities had published such geospatial rules as PDFs, where the areas were marked on map images without coordinates. In these cases, city officials noted how areas were interpreted favorably by operators. Now, coordinate-based restrictions achieved better compliance. However, basing compliance on recorded GPS signals in urban environments also entails challenges, as noted by a city official:

We can't seal off a too large area so that it spills over to other streets, and we must not make it too small either, because then there will be no effect, so it is like finding a good balance on how big a large polygon you draw. And it probably still differs with 20 meters with this technology as well as so it's all about fine-tuning. City Mobility Program Manager 5 (EU)

Privacy is another issue following the implementation of digital rule-setting and compliance. This concern arises from the data model used by MDS to transfer data from e-scooter operators to cities. This model is based on individual journeys and vehicle status changes within an e-scooter fleet. While cities are carrying out various activities, such as planning physical infrastructure and monitoring compliance, they may inadvertently violate personal privacy. Even though no data about travelers is transferred (these data are available to the mobility companies but are not transmitted via MDS), distinct travel patterns that MDS conveys can be combined with other data sources to track individuals and their travel (Carey, 2021; Descant, 2020). To comply with local data protection laws (like GDPR in the EU), some cities work with aggregated versions of MDS, obtaining consent from data owners, or point to public remits, justifying the processing of such personal data.

4.3. Governing relations

Given the substantial impact e-scooters can have in urban lived environments, the interviewees described how MDS has been instrumental in governing the relationships between the different stakeholders in a city.

A common theme across interviewed cities is the setting of an operator's fleet size. The dilemma for cities is to create a fair distribution model among operators (allowing all permit-keeping operators to compete fairly) while meeting the demands of citizens (who may prefer certain operators over others). To this end, most cities use MDS to settle such distribution issues, as explained by a city official:

So, for example, for the entire city, there was a limit, I think of maybe 3000 devices in the entire city, there could only be 3000 devices deployed. Each company got a slice of that, like you know, this company got 750, this company got 1000, and so the companies would come to us and say 'hey we want an additional 500 devices next week' or something like that, and we would go and look at the [MDS] data and say 'well over the past month you've averaged this many devices deployed per day. You've averaged this many trips per device per day, and we had a threshold you had to exceed'. I think it was three trips per device per day for scooters over a full month, you had to have at least three trips per scooter that you had out there in order to ask us for more. City Mobility Program Manager 3 (US)

Another recurring example is how cities use MDS to ensure that all parts of the jurisdiction are served appropriately. To this end, permit programs in the US typically include equity requirements, which require operators to balance their fleet geographically so that all areas of a jurisdiction are served (not just those with the highest profit opportunities), as explained by an operator representative:

And how do we not kill the market, that's a phrase that the vendors always use, where we don't require you know, 33.3%, 33.3%, and 33.3%. So, we decided, OK, the most popular area for riding is area three, and we're going to leave that at 60% of all vehicle deployment. The other two will be 20% and 20%, and so when we proposed that to the vendors, they immediately said yes because I think they felt that the city was going to make an equal distribution for the three, which would hurt their business. And so through our [third-party software], we have a 10 AM time check where those percentages have to be met per vendor. City Mobility Program Manager 4 (US)

In addition, the use of MDS data has been used in several instances to settle e-scooter program disputes and complaints.

We do have residents who hate this program, and we have some disabled residents who absolutely hate this program, and one of the challenges with having a scooter program is the liability that it creates for access, and my priority is trying to mitigate any sort of lawsuit coming from the program. […] We try to address [citizen-reported issues], and we've even had to move some of the drop zone locations for scooter vendors so you know…the way I explained it to them, you want to be a good partner in the community, if this drop zone in particular is upsetting this individual, or this business, we can shift it. We can always make quick changes [using rules API in MDS], and those are small wins. City Mobility Program Manager 4 (US)

Many complaints concerned scooters blocking the accessibility of streets for both citizens and businesses. In these cases, MDS enables a city official to assess the extent of the issue and settle disputes using MDS data as evidence. In such cases, a city official can show, e.g., how many scooters were dropped off at a specific location, which frequently is less than perceived. Three interviewees also describe how this data was used in community meetings dealing with local e-scooter operations:

In some of the community meetings that we've had people are just so insistent in saying that they don't see scooters there ever. And then we'll show them that data, and you know, that's it, it really ends the argument… Because community meetings can be so contentious sometimes, and sometimes we can't even finish the meeting because the residents of the community are so upset, and you can't reason with them. So, when you can provide them with actual metrics and say look, this is your street, this is your business quarter, this is your neighborhood, it makes it a lot easier. City Mobility Program Manager 4 (US)

Finally, respondents describe how they use MDS data to report and argue for political leadership in the jurisdiction.

4.4. Predictability

The final theme is how MDS is used as a mechanism to create predictability in the regulatory process and, by extension, to build trust between operators and cities. Several interviewees point to the benefits of having a standardized, comprehensive dataset on which both parties agree. Such a dataset can serve as common ground, as elaborated by a city official:

The data was away for all of us to be like, "here's one common thing that we think we can all trust and kind of base our conversation off of", and a lot of the conversations we had with those companies as the program was going in some way or another related back to the data. So, it gave us a conversation starter if you will, or places to come together, and even if we were disagreeing, it was at least a common thing to talk about. Information Technology Specialist 1 (US)

Based on the MDS data (and as mentioned above), cities create both periodical reports as well as prompted assessments of the situation on the ground. The periodical reports include any infringements of current regulations for each operator during the specified period, and the operators are typically summoned to meetings after the reports are compiled. In these meetings (typically encompassing all operators), a city representative reviews the status of each operator, both regarding infringements but also improvements since the last review meeting. Using this process, most city representatives report seeing a gradual and significant reduction in the number of violations over time.

An essential theme is the algorithmic complexity required to produce predictable results that adhere to a city's policies. This complexity is especially pertinent for cities that developed their support in-house, as explained by such a city's representative:

Analyzing the data, preparing it in order to be analyzed, and the algorithms to come up with those policy metrics was very challenging, very challenging, and it wasn't like a one-time thing where we worked through the problem, and then we figured it out and then we stuck with how we calculated that metric. It never went away, we were just always talking about that and looking at new ways of calculating it.. Information Technology Specialist 1 (US)

To this end, all but one interviewee prefers using third-party compliance checking software from specialist firms with a deep knowledge of MDS and efficient ways of calculating compliance metrics. However, some respondents also note that relying too heavily on third-party compliance software decreases an authority's decision transparency, which ultimately affects commercial operators. There are open court cases in two cities where operators contend that city rules were not infringed. While the cities and operators agree on what MDS data pertains to the matter, they have different views on whether rules, were infringed (in essence, the operators question whether the algorithm works correctly).

Another issue that cities struggle handling is while the MDS data provide a comprehensive view of current scooter operations in a city, they are not an absolute truth. Issues like the abovementioned GPS signal offset, vehicles experiencing connectivity issues, different physical equipment, varying ping rates across operators, and slightly different implementations of MDS among operators contribute to creation of a dataset where rules cannot be applied directly. To this end, some cities add safety margins into the official rules, as explained by a city official:

For instance, we have rules for a vehicle to be inaccessible for the customer for a maximum of 24 hours and a maximum of 72 hours as parked and not used. […] But I have entered a limit that companies can't see, and that is 48 hours and 144 hours for these so that it is doubled. I double the limit and use those violations in my report and bring them up in our meetings with companies. City Mobility Program Manager 7 (EU)

5. Discussion

The development of MDS and its implementation provides valuable insights into data-driven policymaking and compliance. City decision-makers when creating and revising policy now have access to a rich spatial-temporal data set, in terms of depth, breadth, and timeliness, to provide guidance on what is required to accommodate the needs of the various stakeholders. Through algorithmic support they can use data to evaluate the potential impact of policy, and once a policy is promulgated can monitor its effects. Given this substantially increased predictability (Nabli & Nugent, 1989; Shi et al., 2017) we conjecture that greater data richness increases the speed of policy formulation and revision:

Proposition 1 - The richness of spatial-temporal data will change the speed of policy revision.

Rich digital data gives policymakers insights into the effect of their decisions both at a macro and micro level. At a macro-level, they can learn about city-wide effects, such as the shift between modes of travel and the impact on congestion. A policy that covers many citizens needs to be carefully formulated and remain fixed for an extended period as large-scale change is disruptive and new patterns might take time to emerge. On the other hand, a policy that affects a small of number of citizens could be flexible and amendable quickly. When a policy can be implemented digitally, then we assert there is an opportunity for a distinction between fixed and flexible policy with different methods of revision involving distinct policy decision levels (Heclo, 1974). For example, flexible policy might be amendable by a sub-committee that meets weekly to review operational data and can create new edge decision rights. Given these findings, we thus suggest our second proposition:

Proposition 2 - Policy will be formulated as fixed or flexible with different amendment rules

We now consider the possibilities of flexible policy by adapting the notion of edge computing, which occurs at or close to where data are generated, to conceive of *edge policy formulation*. For a city, the edge is where an e-scooter impacts a citizen or public resources, such as a pavement or park. This means decision rights need to be allocated so that the edge of e-scooter operations can be precisely adjusted very rapidly. We envision that certain city officials will be given the right to make very prompt edge decisions using data generated at the edge and will enable more fine-grained governance of relationships between city stakeholders (Lipsky, 1980; Nabli & Nugent, 1989). These edge decisions will be of a micro nature (e.g., prohibiting scooters from operating in certain areas of a park where young children play) and will conform to legislated policy principles, as conveyed by our final proposition:

Propositions 3 - Data from the edge will enable moving some micro-decision rights to the edge to enable responsive revision and implementation of policy.

The three propositions are a pre-theoretical contribution, as we are still learning about the phenomenon. We need to learn more about the behavior of the key stakeholders and the variations in their interactions before we can make a well-informed theoretical contribution, especially in the under-studied area of edge policy formulation.

6. Conclusions and Implications

In this paper, we have investigated how cities may govern public resources such as roads when the data streams available encompass all activity within a jurisdiction (in our case, vehicle movements).

Our first research question concerns the interplay between policy and data. An important finding in this vein pertains to how ubiquitous movement data influences policymaking. Here we found that access to these rich data streams enables civic servants to engage in a continuous process of detailed micro policy tuning that we refer to as edge policy formulation. Moreover, since these edge policies can be formulated and enforced on this exact level (like a limited section of a pavement), there is a need to develop policies that accommodate and transfer necessary decision rights to the edge.

Our second research question examines the implications for data standards conveying such vehicle movements. Here, our main finding is that the high levels of data richness as exhibited by MDS (e.g., all vehicle movements and other essential status changes) is instrumental in enabling edge policy formulations. Moreover, MDS has not only allowed cities to follow up on rule compliance algorithmically, but it has also served to arbitrate disputes relating to e-scooters involving both citizens and operators.

However, data richness also poses challenges with important implications for cities. First, detailed movement data may infringe on citizen privacy (even when rider data is omitted as in MDS) (Clarke, 2019) and are thus inherently in conflict with data protection legislation such as GDPR and CalECPA. Suppose agencies continue using such ubiquitous data streams for policy matters. In that case, more data aggregation is needed (to make individual tracking impossible), or, agencies need to anchor support for this type of data collection within their public remits. Second, although all relevant recorded data are transferred to cities, these data points will not be a perfect representation of the situation on the ground. GPS signals have offsets, and it is difficult for policymakers to mandate vehicle hardware requirements. Consequently, even in circumstances where the data streams are as rich as in MDS, policymakers need to make transparent choices on the level of strictness with which rules will be enforced vis-à-vis reported data. Third, rich datasets, like those conveyed through MDS also require substantial resources and know-how to leverage the promise of connected vehicle data for policy learning. Here, our study indicates that developing the necessary information systems in-house is a complex and continuous endeavor. To this end, cities seem to prefer procuring specialized third-party software. However, when policy formulation and compliance (and by extension related policy learning) becomes as intertwined with technology as in our case study, there is an inherent risk that *de facto* knowledge of how public policies' rules and regulations are developed and enforced, becomes too opaque to city stakeholders. To this end, it appears as if increased algorithmic transparency is s necessary to mitigate this effect.

Our work is subject to limitations that offer opportunities for further research. Given that our empirical explorative, early-stage results are based on a single-case study of connected vehicles, we envision two promising avenues for future research. First, we call upon researchers to conduct more in-depth research into other contexts investigating transferability of our findings (policy learning under ubiquitous datasets). Second, while our data analysis has generated three empirically grounded propositions, we see a dire need for quantitative testing of these hypotheses.

This research has been an initial examination of the impact of rich (deep, broad, and timely) digital data on policymaking and compliance in a few cities. It gives us a glimpse of how cities can jointly develop open standards for operational data generated by activities within a city, how commercial organizations can convert these data into information, and how cities can use this information to formulate and enforce policy.

7. References

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