2021 IEEE Global Conference on Artificial Intelligence and Internet of Things (GCAIoT) | 978-1-6654-3841-4/21/$31.00 ©2021 IEEE | DOI: 10.1109/GCAIoT53516.2021.9693025

Mobility-as-a-Service Challenges and Opportunities in the Post-Pandemic

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***Abstract*—In December 2019, the world experienced a pandemic that called into question what we always took for granted, such as our freedom of movement. Tough restrictions imposed across the world were necessary to stem the transmission of the COVID-19 virus and have largely affected the mobility and transport sector. In a first phase, due to the mandatory confinement that forced people not to leave their houses; in a second phase, when the measures eased and people started to have the need to move again, it was necessary to look for alternative means of transport that avoided the gathering of people. In view of the advances that were being made in recent years towards a Mobility-as-a-Service paradigm that advocates multimodal and shared transport, the pandemic has raised many challenges. In this paper, a statistical analysis of the mobility data made available by Apple from January 2020 to March 2021 is presented, where the reduction in the use of public transport becomes evident, leading us to question what the future of Mobility-as-a-Service will be as its foundation advocates, among other aspects, the use of a shared transport model. Despite the challenges that the pandemic has brought to Mobility-as-a-Service, a set of opportunities are presented that can be used in the short and medium term to strengthen the paradigm and enhance its massive adoption.**

***Index Terms*—Mobility-as-a-Service, COVID-19, Post-Pandemic.**

I. Introduction

Smart mobility is one of the two indicators, alongside governance, which assumes greater relevance in the classification of a city as being smart [1]. In the last decade, we have witnessed a paradigm shift in the transportation of people and goods, moving towards the new Mobility-as-a-Service (MaaS) paradigm, which aims to change the vision about mobility, progressively moving from the individual model of using private cars for a shared model. This change will require a holistic change in the society and will be a fundamental piece to meet the 17 sustainable development goals (SDGs) defined by the United Nations for 2030 [2], thus improving the quality of life for citizens [3].

The growing world population density, with a large agglomeration in cities and urban areas [4], where an estimated 8 billion people existed in 2020 and 9 billion are expected for 2040 [5] [6], has received more and more attention and actions to ensure a mobility in the future that is more equitable, sustainable, efficient and convenient for citizens [7].

This was the direction and path of urban mobility in the pre-COVID-19 era, before, on March 11, 2020, the World Health Organization (WHO) declared COVID-19 to be a worldwide pandemic. This pandemic resulted in significant changes in many aspects of the society, which also included, to a considerable extent, the mobility of citizens. Well-established mobility patterns were called into question, and the need for social distance as well as lockdown led citizens to reduce their movements and change their mobility patterns, avoiding crowded mass transit. It is believed that many behavioral changes that have occurred will remain in the post-COVID-19 era [8]. These significant changes represent challenges for the future of MaaS.

This paper presents two main contributions: one that deals with the statistical analysis of mobility data from 63 countries over a period of 15 months and another that focuses on the opportunities that lie ahead for the MaaS in the post-pandemic period. The rest of the paper is structured as follows. Chapter II presents works related to mobility in the times of COVID-19. Chapter III presents a statistical analysis of mobility data. Chapter IV presents several opportunities for the MaaS in the face of the pandemic we are experiencing. Finally, in chapter V, the main conclusions of this study are presented.

II. Related work

In this section, a review is presented of contributions from 2020 and 2021 related to the keywords ”mobility + COVID”, obtained from the scientific repository IEEExplore. From a total of 60 papers obtained based on the relevant keywords for the present work, 11 papers were chosen, through the analysis of the title and abstract, which are analyzed in more detail in this section.

The unprecedented pandemic we are experiencing has significantly accelerated data analysis and the development of predictive models on the effects of mobility on the transmission of a highly contagious virus, in the same way that it has fostered the development of new technological solutions to prevent, monitor and fight the spread of a pandemic. The following are recent scientific contributions that focus on predicting the impact of mobility and on technological solutions to assist in the safe mobility of citizens.

In [9], an approach based on Machine Learning is presented in order to understand the profile of travelers in the group 16-59 years old and over 60 years old (most vulnerable group). The perception of the mobility profile allows managing and recommending routes using the London Underground and Overground (LUO) Network in order to reduce the number of people, the main form of transmission of the COVID-19 virus. Technologies such as WiFi, RFID, Bluetooth and UWB are also used as part of the solution to accurately determine people's position.

In [10], authors present a study that aimed to perceive how people moved during a given period of the pandemic COVID-19, based on a tracking infrastructure placed at 81 points of interest (POI) on the island of Madeira, in Portugal. The data collected, combined with official data from infected people and data collected via crowdsourcing, feed a web application with information on the mobility of people with two main objectives. On the one hand, stakeholders have access to a visual tool to contrast the diffusion of COVID-19 by monitoring human mobility and, on the other hand, citizens have access to real-time access to the number of people in a given POI and therefore are able to plan better and with more information their daily activity.

In [11], New York City's bike sharing system is analyzed in order to gain insights into the socio-economic variables that influenced urban mobility during the pandemic period. The study explores several sources of data in order to analyze the relationship between bike sharing, public transport, and other modes of transportation, making it possible to infer conclusions about future urban planning. This case study presents the main trends of the last year and the data analysis allows us to understand the consequences that the pandemic may have on the expansion of the infrastructure of the bike sharing system.

In [12], authors present a framework that aims to make the use of transport safer, monitoring the number of people inside buses, verifying the use of masks as well as the necessary physical distance. Deep Learning, thermal imaging and sensor technologies algorithms are part of the architecture of the proposed solution.

In [13], authors explore the relationship between various factors that influenced mobility such as containment and closure policies, disease trends, and human mobility patterns in 40 countries in Western, Eastern, Northern, and Southern Europe and North America. The model parameter estimations allowed to conclude that the total number of cases, the cancellation of several activities (schools, events, remote work), mask policies and the pandemic declaration all were significant predictors of change in workplace mobility from baseline.

In [14], authors analyze the quantitative effect of the lockdown in the various regions of Austria and present an analysis of the changes at the mobility level based on the real-time information collected anonymously from data from mobile phones. As a methodology, a data aggregation pipeline is used that allows an analysis of mobility at certain points of interest (POIs), an analysis of individual trajectories and the investigation of the cluster structure of the source-destination graph. The analysis verified a reduction of people in the metro stations in the order of 80% and an individual travel radius less than 500 meters have duplicated. The authors conclude that an analysis of data from mobile phones allows the quantification of a country's behavior in terms of mobility and that, therefore, it is important that these anonymous data is available to be used in future similar situations.

The mobility of citizens and the way it promotes high social mixing are decisive factors in the spread of the COVID-19 virus, and which directly impacts the number of people infected and the number of deaths. In [15], the authors use a generalized spatiotemporal model that aims to quantify the role of high social mixing and mobility in the spread of the pandemic through a composite latent factor. The study presents tests done on mobility, the number of infected and deaths in New York City in order to prove that places with high inter-zone mobility effectively have a sync in peaks of the daily exposed curve as well as similar social mixing patterns. One of the study's conclusions regarding the effect of lockdown on mobility points to future directions for the design of intelligent mobility strategies and quarantine procedures to curb infection spread.

In [16], authors propose a mobility-based SIR model for pandemic situations supported by the assertion that an epidemic becomes a pandemic due to the existing connectivity between different regions of the world and the non-uniform distribution of the population and its social coherence. The proposed model shows the significance of social connectivity and mobility during a pandemic taking into account the local and the global transmission rate of the infection. The model was simulated taking into account three different origins of the infection, namely random location, weakly connected location, and strongly connected location. The simulation results show that the limitation of social connectivity reduces and delays the peak of infection and that restricting mobility from the top-10 percentile of connected locations can reduce the number of infected individuals between 18% to 27%.

In [17], the effects of mobility trends and seasons on COVID-19 cases are analyzed based on a Generalized Linear Model using the Negative Binomial Regression. The study includes, for the period Feb 15 - Nov 15, 2020, data from four countries (Austria, Greece, Italy and Czech Republic), consisting of daily observations of new cases of COVID-19 and six types of mobility trends: retail and recreation, grocery and pharmacy, parks, transit stations, workplaces and residential mobility. The study results suggest that there is a direct relationship between the number of COVID-19 cases and the seasons as well as different mobility trends.

In [18], authors present a wearable device whose objective is to promote the mobility of people in the post-pandemic, countering the exaggerated need to be at home and the negative consequences that this entails for people for economic purposes and physical or mental health. The study features EasyBand, an Internet-of-Medical-Things (IoMT) smart wearable device that, through its sensors, can detect people within a radius of 1 to 4 meters and give information, based on a three-color scale, about the likelihood of the person being infected.

In [19], authors present a framework that makes use of the concept of Social IoT (SIoT) to allow pedestrians to navigate safely, thus mitigating the risks of exposure to the virus in areas with high population density where physical distance may not be entirely easy to comply with. The framework includes a real-time routing algorithm considering other devices 'mobility. Clustering techniques are applied to IoT devices, taking into account two criteria: location of the devices and the friendship levels among their owners. Using the Dijkstra algorithm, where weights represent security levels, routes that make a trade-off between both safest and shortest paths according to the pedestrian preference are recommended.

III. Mobility Analysis

This section presents an analysis of the mobility data provided by Apple [20], from January 2020 to March 2021. This dataset presents information on three types of means of transport (walking, driving and mass transit) by country. Of the 63 countries existent in the dataset, the ones that most contributed to the data were United States, Japan, France, Germany, Thailand, Mexico, United Kingdom and Switzerland, representing 80.7% of all cases. It is for these countries that the statistical analysis of this section will be carried out. The distribution of transportation by country, where "Driving" is the most used type of transport, with 68.61% of the cases, is shown in Table I.

TABLE I
Cross Table Country*Transportation

	Transportation			
Country	Walking	Driving	Mass Transit	Total
France	33	45	15	93
Germany	31	40	18	89
Japan	63	108	53	224
Mexico	23	32	13	68
Switzerland	21	3 1	12	64
Thailand	30	43	13	86
United Kingdom	22	23	21	66
United States	547	2255	264	3066
Total	770	2577	409	3756

We started by verifying if transport is independent of the country. Using a chi-square test we obtained a p-value = 0, less than the 0.05 significance level, that allows us to conclude that transportation is not independent of the country where it is used. To answer the question, "What is the effect of transportation (factor 1) used and country (factor 2) on monthly mobility?", we use MANOVA (Multivariate Analysis of Variance) test. As some assumptions are not fulfilled, the Pillai trace was used to draw the conclusions because it is a more robust test. What we want to verify, for each of the factors is: H0: there is no difference between monthly mobility average vs H1: there is a difference in at least one monthly mobility average.

A. Transportation effect

MANOVA test showed that there is an effect of transportation on monthly mobility average [Pillai trace = 0.586, with p-value = 0.000 below the level of significance 0.001]. Subsequent univariate ANOVAs confirm the effect of transportation on average monthly mobility (p-value = 0.000 $<$0.001) and the Tuckey post-hoc test showed that there are significant differences between the group of individuals using "Driving" and "Walking" relatively to the group of individuals using "Mass transit" (p-value=0.000 $<$0.05).

B. Country effect

MANOVA test showed that there is an effect of the country on the average monthly mobility [Pillai trace = 0.605 with p-value = 0.000 $<$0.001]. The subsequent univariate ANOVA shows that only in January and February 2020 this effect is not significant (p-value $>$0.001). The Tuckey post-hoc test, with a 5% significance level, allowed to verify the significant differences between the monthly mobility averages between each country, for the remaining months, with a p-value $<$0.05.

C. Interaction effect of the two factors

The interaction effect on mobility was analyzed with a 0.001 significance level. The hypotheses to check are: H0: there is no interaction of the two variables in the average monthly mobility versus H1: there is an interaction of the two variables in the average monthly mobility. With a Pillai trace = 0.338 and a p-value = 0.000, it is concluded that the two variables together also have effect on the average monthly mobility.

To visualize this effect, Figure 1 to 6 show the estimated mobility averages by country and transportation in some selected months. In February 2020 it is possible to verify that all types of transport, including "Mass Transit", were above the base value 100. France and Germany are the two countries where "Mass Transit" is the most used means of transport. In March 2020, the month in which the pandemic was declared by WHO, all countries considered in this analysis (the most representative in terms of data), drastically reduced their mobility in the three types of mobility, all of which registered average values below the base value 100, except for the "Walking" type in Japan. In April, with the first generalized lockdown in many countries, values were found, in the three types of mobility and in all countries, below the average value of 80. This was the month, in the entire period of 15 months analyzed, with lower mobility average values. From May, mobility started to rise again. In July, "Walking" and "Driving" mobility were already above the base value 100 in all countries; the same is not true for the "Mass Transit" type, which was only above this value in 3 countries (France, Germany and Japan), showing an evident reduction in this means of transport. September was the month in which "Mass Transit" had higher average values, with only two countries below the base value (United Kingdom and United States). From October onwards, there is a further generalized decline in mobility again. In December, only France was using "Mass Transit" with a value above base 100. In March 2021, a new increase in the use of "Mass Transit" is already beginning to be observed. The statistical analysis carried out allows us to conclude that the "Mass Transit" type was the most affected during the pandemic, due to the fear perceived by citizens that it represents a greater possibility of transmission of the virus.

IV. Opportunities for MaaS in the Post-Pandemic

The concept underlying the MaaS takes on a different paradigm than what is currently seen in most countries, where

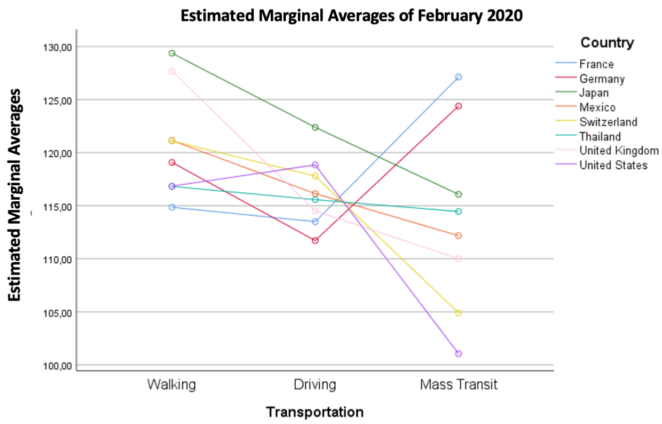

Fig. 1. Estimated Marginal Averages of February 2020

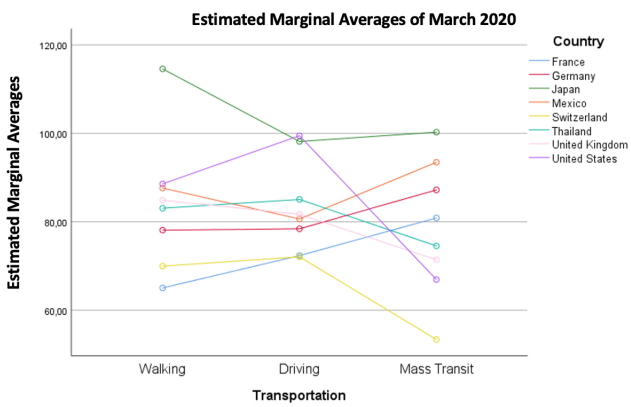

Fig. 2. Estimated Marginal Averages of March 2020

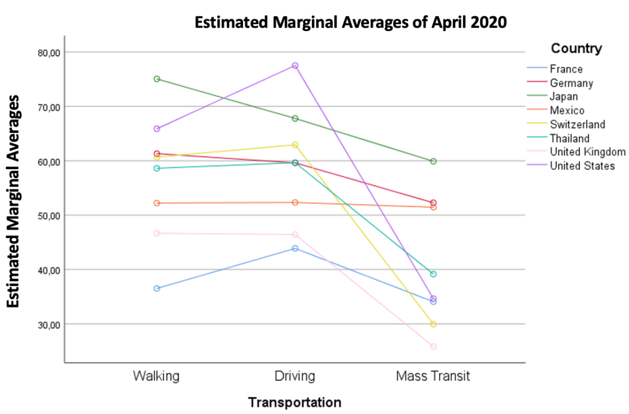

Fig. 3. Estimated Marginal Averages of April 2020

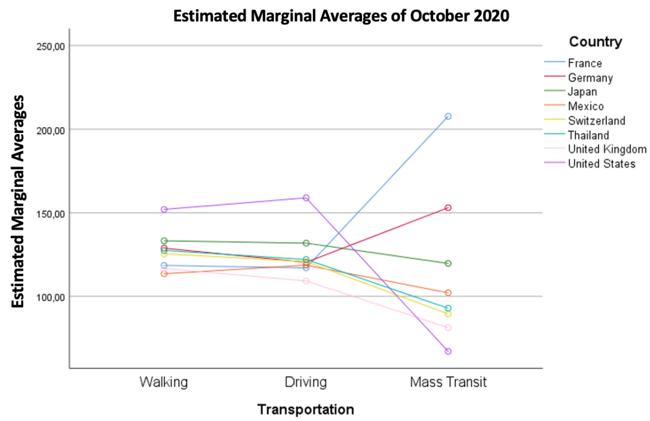

Fig. 4. Estimated Marginal Averages of October 2020

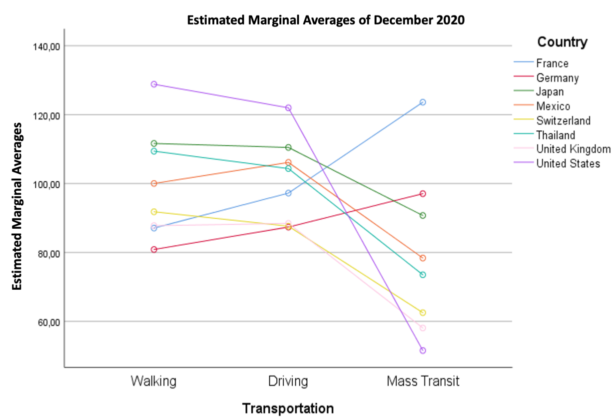

Fig. 5. Estimated Marginal Averages of December 2020

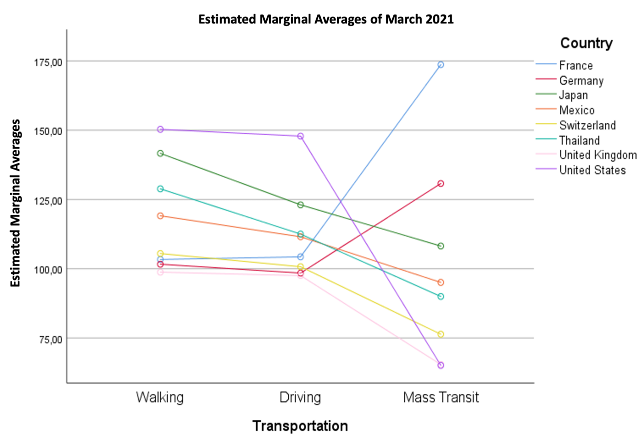

Fig. 6. Estimated Marginal Averages of March 2021

the use of the private car is still a reality. MaaS assumes the use of shared public transport, rideshare, carshare or carpooling. These means of transport were especially affected by the pandemic, where one of the main measures taken globally was to drastically reduce contact between people and increase physical and social distance. The question then remains: What is the future of MaaS in the post-pandemic period, in the short and medium term? More than trying to go back to how things were, it is important to embrace the new ”normal” and understand what opportunities COVID-19 can bring to the future of mobility and MaaS services in particular.

Fig. 7. Opportunities for MaaS in the post-pandemic

Figure 7 illustrates some of the main opportunities [21] [22] [23] for MaaS in the post-pandemic which are also detailed below.

1) **Reinforce the Core and Central Idea of MaaS**: The main idea behind the MaaS paradigm is the ability to take a person from an origin to a given destination, in a multimodal way, without the citizen knowing at the outset what type of transport he will use. The main idea is to do it in the quickest way (or another criterion that is most important to the citizen) and, now, also in the safest way. The opportunity lies in taking advantage of the multimodal concept and the added value it brings and more resilient the city will become.
2) **Safer Decision Making and Route Planning**: The pandemic that we still experience today can help to redefine MaaS services by helping them to become more resilient and prepared for future pandemic situations. Resuming the use of public transport by citizens will be as easy as the level of security they offer and the low risk of infection. This means more cleaning, protective glasses, air filters and less congestion in transports. Here lies an opportunity for MaaS providers as they can make information available to citizens to help them plan their routes more securely, providing real-time information on the number of people in transport, time-in-transit and even frequency of cleaning. Therefore, MaaS solutions will contribute to the enhancement of safer decision-making for citizens.
3) **Quick Adjustment to New Economic Situations**: From the combination of the two aspects above, a new opportunity arises that emanates from the pandemic and the economic difficulties that many families face. The criterion of speed of travel can now very easily be surpassed by the cost of it. With the integrated information of the various means of transport in terms of costs, MaaS services can be of benefit to families that have been affected by the economic situation and who need to be informed of the most economical routes to travel.
4) **Increased Awareness of Other Forms of Transport / Mindset Shift**: The pandemic required lockdown in almost every country when they faced the first wave of high numbers of infected people. With the progressive lifting of restrictive circulation measures, there has been a search for alternative means of travel, such as bicycles, which can foster cultural change with regard to the form of mobility and a change in the culture and mindset of citizens which is fundamental to happen so that the MaaS can assert itself. If in some countries, such as the Netherlands, this change was not so evident as there was already a strong culture in terms of using alternative means of transport other than private vehicles, the same did not happen in other countries such as the USA where there was a strong cultural precedent for the use of the private car.
5) **New Business Models**: The pandemic forced citizens to change their habits and, inevitably, transport companies also had to do so to keep up with new needs. Rideshare companies, for example, started to transport goods and food, instead of the traditional transport of people. This became necessary given the impossibility for people to leave home and still need access to basic goods. New business models emerged as a result of a necessary adaptation to the change in mobility habits. The Dutch government, for example, encouraged citizens to plan ahead their mobility needs and reduced spontaneous outflows. In terms of mobility service providers, this implied a redefinition of the service offer: advance reservations increased because citizens needed the certainty that on a given day they needed to have a vehicle, contrary to the previous trend of always having a vehicle available at any time. On the other hand, the pandemic undeniably brought a digital acceleration on the transports sector, through new solutions such as contactless payment and ticketing solutions and real-time information from buses or trains that started to be available for citizens.
6) **Free Space Reuse**: The effect of the lockdown witnessed world-wide was too evident in the movement in the cities and in the number of people. Suddenly, the streets that previously had no space to house vehicles, started to have a lot of unoccupied space, which made the discussion and debate about how space should be used in cities resurface in order to prepare a better future. The introduction of active and more sustainable means of transport has begun to take place in several cities, which may pave the way for multimodal forms of transport to assert themselves in the medium term as a result of the infrastructures that have emerged in the meantime.

In New York, more space was added for cyclists and micro mobility users. In Bogotá, 76 kilometers of cycle lanes were created overnight to promote social distance. Mexico City and London, whose cycling networks had been introduced for several years, have moved towards making some measures more permanent.

7) **Greater Availability for Data Sharing**: As a way of increasing the response to the pandemic situation, we have witnessed a greater sharing of information between the entities that started to work in an organized way in the sharing of data for a greater and common good. This greater sharing facilitates data integration, facilitating data collection and processing to generate relevant information for MaaS providers and, consequently, for citizens.

V. Conclusions

The pandemic that plagued the world in 2019 and that still affects us in different dimensions of our daily lives, has radically changed the mobility habits of millions of people around the world. This paper presented a statistical analysis from January 2020 to March 2021 that focused essentially on understanding what happened in this period in terms of the type of mobility and country. One of the most affected types of mobility was the mass transit by the cluster of people that implies and that raises the question of the future of MaaS, which includes shared transport in its genesis. In this paper, several opportunities were also presented, even in the face of existing challenges, which can be envisaged for MaaS in the post-pandemic era. The following are highlighted: reinforce the core and central idea of MaaS, enhance a safer decision making and route planning, quick adjustment to new economic situations, increased awareness of other forms of transport / mindset shift, new business models, free space reuse and greater availability for data sharing. Although the pandemic we are experiencing has raised numerous challenges, it is in times of adversity that new opportunities emerge, so MaaS providers will necessarily have to adapt to the new normality and take advantage of the change in mobility habits we are witnessing so the paradigm of MaaS can assert itself in the coming years.

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