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Research Paper

The effects of mobility on the COVID 19 pandemic: Case study the Metropolitan Area of Mexico City

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Abstract
The current COVID 19 world health crisis has been largely due, among other factors, to the easiness of today's society to move between areas and regions in the territory. The patterns of movements and personal contact, as well as the possibility of traveling long distances in a relatively short time, have favored the growth of the pandemic phenomenon. Many human activities have changed in their performance, and many of these changes will remain in the future. Limitations to mobility have been a favored strategy by governments in an attempt to combat the spread out of the virus. Since the outbreak in Wuhan, China, governments have imposed severe travel restrictions on all modes and transportation in order to control the pandemic. The purposes of this paper aretwofold; todevelop a cognitive framework based on complex systems to frame the pandemic and, to measure the relationship between COVID cases and person trips. A correlation model applied to the Metroplitan Area of Mexico City shows that there is a high correlation between the two varariables.
Keywords: *Urban Mobility, SARSCOV 2, Complex Systems, Urban Dynamics.*

I. Introduction

No one could foresee at the end of 2019 that the new virus, discovered in Wuhan China, would reach such high levels of contagion nor the negative consequences it would have on the postmodern way of life. The disciplines related to health issues were the first to engage in research towards the control of the pandemic as to medicines, vaccines and infrastructure required to fight the virus. Followed in turn studies on the fields of economics, sociology, psychology, etc. in an effort to learn about the impacts that the pandemic could have on the several activities carried out by the population and its effects on human behavior.

The disciplinary field of Architecture and Urbanism contributed in a relatively short period of time with works, mostly speculative, on the effects of the virus in the various aspects of urban life (Honey-Roses et al. 2020; Aloi et al. 2020, Herriges 2020, O'Sullivan 2020; Null & Smith, 2020). Two and a half years have passed since the recognition of the pandemic, and nowadays, the numbers show worldwide more than five billion contagions and more than six million deaths. In Mexico, the numbers have reached at this day almost six million contagions and more than three hundred thousand deaths. (Johns Hopkins University 2022)

The negative impacts of the pandemic have been diverse among countries depending on the geographical, economic, social, cultural factors as well as health infrastructure. Although relative control of the pandemic has been achieved worldwide, there is still an insistence on applying the rules of healthy distance, interpersonal contact and mobility patterns of the population locally, regionally and globally. In the same way, there has been some progress in the distribution of vaccines and the improvement of medical treatments. The idea that the effects of the virus have substantial implications on the forms of social life leads to investigating

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the relationships between the incidence of the virus and the factors associated with the mobility of the population.

Human behavior and virus spread

There is a wide range of biological and social factors associated with the pandemic. From the standpoint of Architecture and Urbanism, the use of space by people and the mobility patterns are associated with the spread of the virus. Human behavior depends on the aesthetic and ethical factors surrounding everyday life and these are translated into patterns that rule the psycho-social activities of the population; since there is broad range of perceptions among the people, the decision system becomes complex. The following graph (See fig. No. 1) depicts this process of decision taking on the basis of the aesthetic and ethical values of individuals and collectivities.

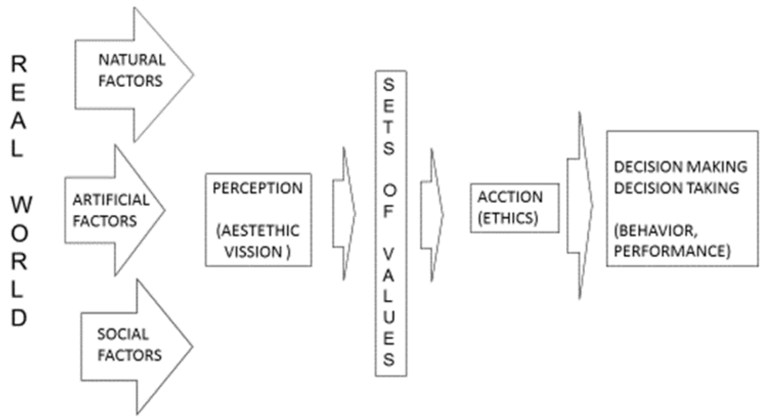


Figure No. 1. Relationship between the aesthetic and ethical values in decision-making processes.

According to the graph, the process starts with the vision of the world filtered by the value system of the observer. The social components feeding the process are components of the moral order, which imply a broad range of human perceptions that complicate the analysis and broaden the alternatives. With respect to the COVID-19 pandemic, it means that it is quite impossible to have absolute control of the spread of the virus given the breadth of bio-psycho-social factors associated with the decision phenomenon. For the purposes of this paper a framework considering a trilogy of factors, namely physical, functional and social, are required to study the behavior of territorial urban phenomena in general. These are pillars in the construction of an epistemic base to support comprehensiveness in the analysis of urban phenomenology. (See Figure 2).

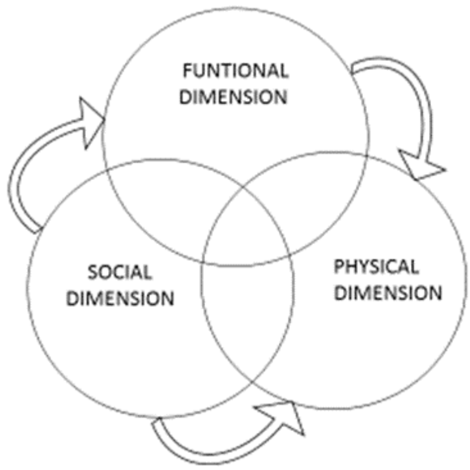


Figure No.2. The three dimensions for the analysis of urban phenomenology. Based on Jiménez et al. (2009).

In the figure the arrows show the codependency between groups of factors; we can notice that the process starts with the social dimension since the ways of life and expectations determine the other two. The physical dimension, which encompasses all the components built in the city, is the result of the construction of living spaces to house human activities in their various categories. In the end, all the factors condition each other, but the influences depend on the direction of the arrows in the graph.

Urban dynamics, mobility and SARSCOV 2 virus: a systems approach

Although the main objective of this paper is to develop a theoretical-cognitive framework to study the spread of the SARSCOV 2 in relation to the mobility of the population, there is also the purpose of developing a correlation statistical model to measure such a relationship. The approach involves a theoretical-methodological discourse based on philosophical, epistemological and theoretical questions around the phenomenon of Urban Dynamics to pivot the arguments about the expansion of the virus in the urban space. As for the philosophical position, it is presumed here that it is a positivist vision of reality for the spatial-territorial phenomenon of the incidences of the virus. The basic epistemes considered here includes the concepts of pandemic, space, city, territory, dynamics, functionality, mobility, and system. Mobility includes the travel patterns of the population, as well as infrastructure and services. The discourse is based on the general systems approach applied to the functioning of the city through the concept of urban dynamics.

The ideas raised in the field of systems dynamics by Jay Forrester in the 1960s (Forrester, 1969) can be considered as the foundations that support the cognitive framework to understand the functioning of the city. These ideas support the rational understanding of the functioning of the city, under the concept of "urban dynamics". Forrester's approach can be related to quantitative methods and models; however, his seminal work allowed a philosophical-epistemic deepening that led to specific theories in all disciplinary fields of the sciences, arts and humanities. From this perspective, applying the approach to the city, we understand it as an urban system whose behavior can be described, understood, discussed and explored on the basis of complex systems.

Given that this document is limited to the development of a cognitive framework that frames the phenomenon of the pandemic in relation to the mobility characteristics of the population, the strategy is to explore the incidence of infections with the availability of infrastructure and transport services for the population. This pandemic-mobility correlation is clearly demonstrated theoretically in the light of the concepts associated with the concepts and theories on systems and urban dynamics through which the complexity of the system can be visualized as a function of the number of elements and their interactions (McLoughlin 1971. Chadwick 1982).

The systems approach allows us to anticipate that the complexity of the system depends on the number of components; however, in a deeper analysis, the levels of exchanges, as well as the size of the activities (intensity) and the profile of seasonal demand, (frequency and rhythm) according to Jiménez, Álvarez and de Hoyos (2009) are determinants in the level of complexity of the system. The number of possible scenarios grows exponentially with the changes that may occur in the attributes of each component, as illustrated in Figure No. 3

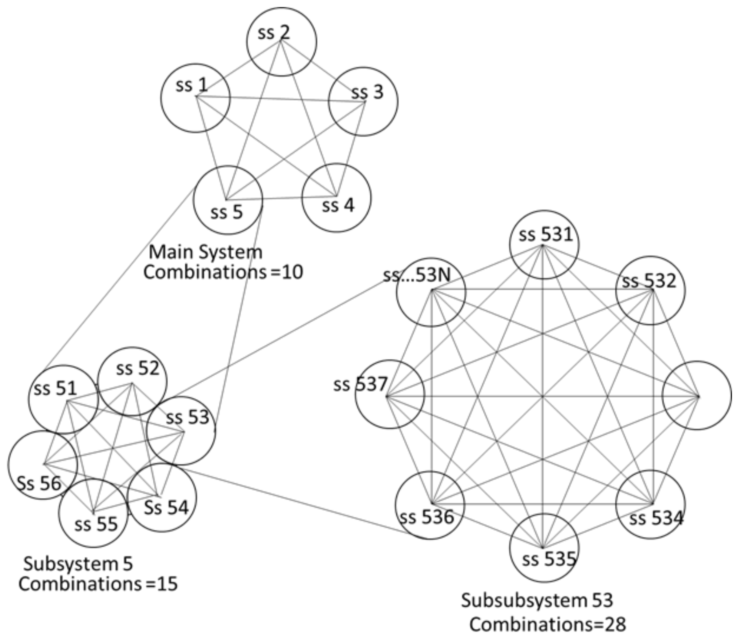


Figure No.3. Complexity of the Urban System on the basis of the number of components

Of course, the range of interaction and possible behaviors can be very wide; however, the need to have concrete alternatives for the solution of problems, and the satisfaction of needs, force us to consider a reduction in complexity in order to manipulate the variables and keep the system under control. Complex systems, per se, are difficult to model due to the numerous elements and their attributes that require more refined techniques and instruments for their study.

Urban dynamics and the complexity of the system

Urban activities require a physical space to be carried out; this implies that as activities increase, the use of land also increases, which, under the same density, leads to greater use of space and greater intercommunication –vehicles, people, goods– and an increase in distance due to physical expansion. This argument leads to an increase in the complexity of the system simply by considering the intensity of activities and flows. Also, as mentioned in previous paragraphs that the difficulty in the analysis increases when considering the ways of life and the behavior of the population which belong to the moral dimension.

The systems approach to urban dynamics brings us closer to a vision of the functioning of the city in terms of urban activities and the exchanges that take place between them. The elements that make up the urban system are human activities (work, education, recreation, circulation, etc.) and the interactions comprise the flows of information between them. These activities are translated in their spatial version as land uses, which are associated with the occupation of a territory and allow the construction of a physical-spatial-territorial image of the city. As for the flows, physical and non-physical information are considered. For the purpose of this research, flows of interest are of a physical nature, such as the number of trips, the number of passengers, the amount of cargo displaced, the number of vehicles, and the like. There is a direct relationship between the characteristics of these flows and the land uses derived from the levels of interaction between the activities in terms of their intensity, their frequency and their rhythm (Jiménez, 1996).

It is clear that we deal with a complex system from the mere quantitative approach and this is simply due to the increase in the number of activities and the relationships between them; however, by including the various social factors associated with human behavior, the operating scenarios are more complicated and consequently, the analysis of the functioning of the city is more difficult. For this reason, is that Jimenez, et al. (2009) propose three dimensions of analysis in the study of urban dynamics; these are: the physical dimension, the functional dimension, and the moral dimension. The latter is the one that seeks to consider the forms and attitudes of the population in everyday life and that allows the inclusion of qualitative factors in the analysis of the characteristics of urban dynamics.

Mobility in the urban dynamics, its role in the expansion of the pandemic

From the angle of architecture and urbanism, design is conceived as a general cognitive instrument through which we order our actions and resources towards the management of spaces adapted for the control of urban life. From the point of view of mobility, this means inducing some changes in the way people move in the city to modify the parameters of intensity, frequency and rhythm of the exchanges between urban activities and thus order the flows of physical movements in the city. There is much evidence of the positive effects on the number of infections due to mass movements of the population – pedestrian flows, vehicular flows, passenger flows by metro and bus and other mass means of transport. (Aloi et all. 2020). This has led governments to reduce the mobility of the population in terms of the number of services available and to impose rules of behavior that lead to the reduction of the risk of contracting the virus while traveling on public transport services, namely buses, metro, taxis, and vans, among others, besides restrictions on social and productive activities.

Under the above reasoning, there is no doubt that the intensity of the pandemic is directly related to the dynamism that the city manifests at a given time. The more human activities that are carried out, the more interconnections will occur between them and the flows of information will grow to the same extent; the larger the size of the activity, the same activity will increase the flow of information within and between activities; the more propensity towards mobility, the more intense the interactivity movements will be. In this way the three aforementioned concepts – intensity, frequency and rhythm of the interchanges in urban dynamics –led to the idea of complexity in the functioning of the system. We can relate this to the phenomenon called "friction of space" widely applied in urban and regional mobility studies, which implies a high amount of information that moves in a certain time and that denotes problems of saturation and congestion in the communication channels. As an illustration of the number of components comprised in the urban transport system, in particular, the following figure (See Fig. 3) shows it the main elements that make up a part of urban mobility.

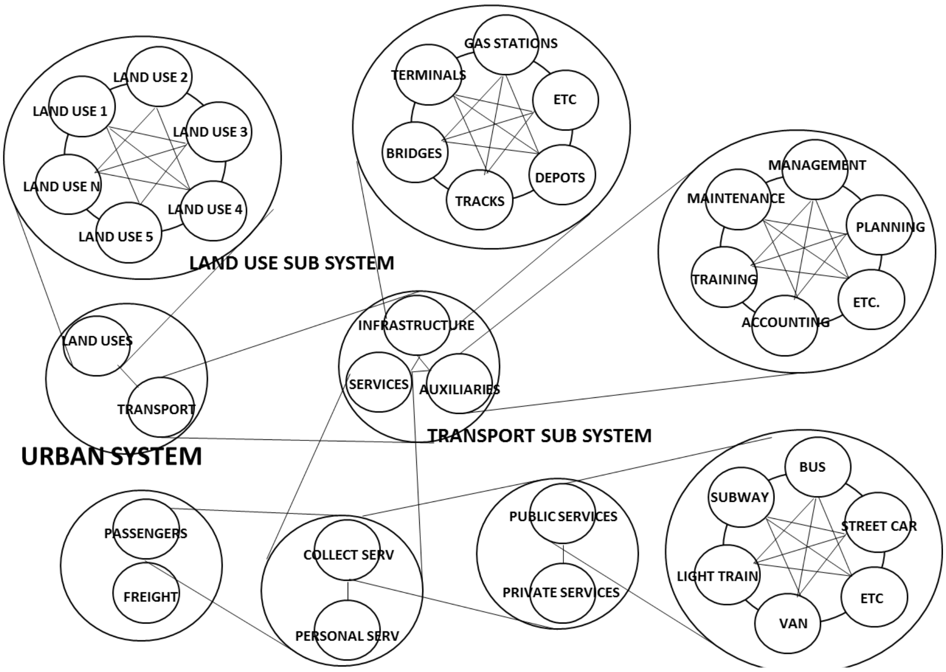


Figure No. 3. An alternative to depict the components of the urban public transport system

From this scheme it can be deduced the large complexity involved in the modeling of the urban transportation system and that it is necessary to reduce that complexity in order to offer practical alternatives that lead to the solution of needs and problems associated from the functioning of the system in the urban dynamics of the city.

The correlation between the amount of COVID cases and population mobility

Once the conceptual framework has been developed above, the second objective of this paper is to measure the relationship between COVID cases with the mobility of the population. This is done by means of a correlation model applied to the Metropolitan Area of Mexico City, formed by the urban areas of the city itself and the surrounding municipalities of the State of Mexico. (See MAP 1).

Map No. 1. Metropolitan Area of México City

As discussed previously in this paper, the analysis of the urban dynamics through the system's approach allows the analysis of the intensity of the virus SARSCOV 2, the number of contagions, with the capacity of the population to move among the diverse geographical areas that conform the spatial urban agglomerate. As it was said before, the level of dynamics is directly proportional to the number of activities and the interactions among them, given the availability of transportation means and services. Again, for the purpose of this paper, the intensity of the pandemic is translated into positive COVID SARSCOV 2 cases and the capacity of movement is based on the number of trips carried out on a daily regular basis by the population in the urban area of interest for this study.

The correlation model

As we know, the lineal association between variables can be computed by means of regression models of the form:

Y=Bo + B1Xi + B2X2+ BnXn +E

Where:

Y= Dependent variable (for the case at hand, COVID cases)

Bo= Parameter in the origin

B1= Parameter for each independent variable

X= Independent variables (for the case at hand, daily person trips)

The general hypothesis is that the number of trips is correlated positively with the number of COVID SARSCOV 2 cases. The ultimate consequence of this is that, as the number of trips increases, so does the number of COVID contagions. (See fig. No. 5):

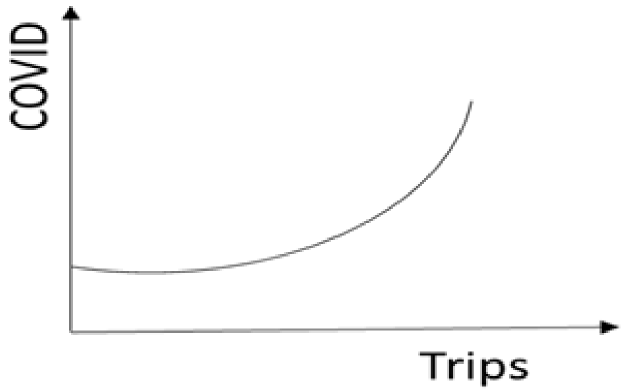
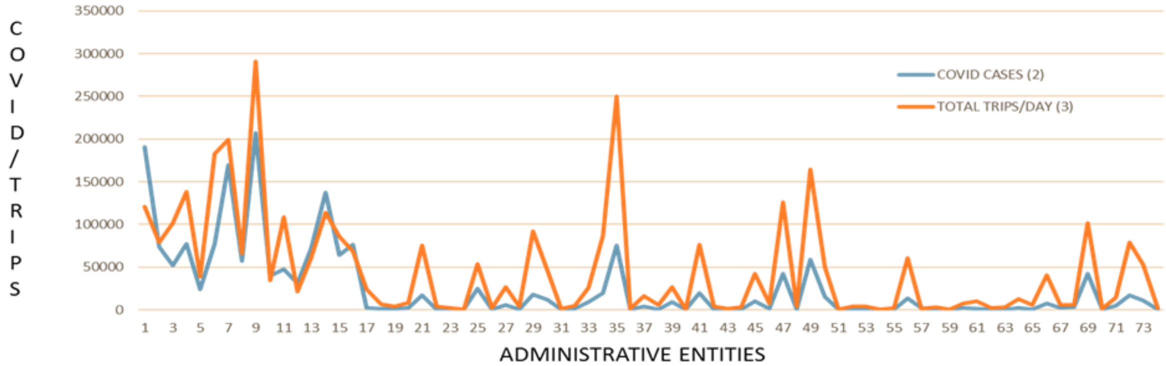


Figure No. 5. Graph showing the positive effect of trips on COVID contagions

The model is quite simple, indeed, but suffices the intention of this paper to measure the correlation between the virus and mobility. The data computations were handled with Microsoft Excel. According to the results, the correlation coefficient between the two variables of interest is 0.82859161 (See annex 2) which means that, in fact, the growth of COVID cases is highly associated to the intensity of trips carried out on a daily basis in this particular urban area. The following graph shows clearly that the data patterns for both variables are basically the same.



Graph No. 1 Patterns of association between COVID and person trips
Note: The amount of trips is divided by 10 for a closer pattern comparison

Of course, we know that correlation does not mean causation, but it can be argued that indeed, mobility should be constrained to reduce the probability of contagions among individuals. This general conclusion can be sustained regardless of the other health, social and economic actions implemented to control the spread out of the pandemic. Limiting mobility per se will contribute significantly to the reduction of infections and will contribute to the principle of the resilience of the city. It is insisted that the patterns of behavior of the population at the individual and collective level greatly complicate the finding of a definitive solution to the problem of contagions. The wide variety of activities and their characteristics induce many interactions among components of the pandemic system, and therefore the patterns of movements become complex. In recent research (CACAU, 2022) the team found a low correlation between the variables related to the characteristics of the urban public space, but a high relationship with the variables related to the transportation system.

The wide variety of manifestations of urban life have been shaken by the limitations of mobility in the population. Both social and economic activities are the ones that have suffered the most in the dynamics of the city. It can be argued that the way of life has changed permanently and that today new patterns are emerging in the uses and customs of the population. The paradigm of postmodern urban design theories is based on the principles of freedom of action and mobility because democratic societies avoid limitations on human and social rights; however, this design criterion is threatened by the pandemic, since control of the virus, relies very much on the restriction of activities and movement in the system. Urban design has to find new criteria, to solve the needs of space and movement without limiting physical contact. Perhaps this is the antithesis of modern design but necessary to assure population health.

II. Conclusions

The phenomenon of the pandemic caused by the COVID 19-SARSCOV 2 virus is related to a wide variety of causal factors of bio-psycho-social order, which together are identified as components of a complex system difficult to control. Within the range of factors are those associated with the characteristics of urban space, as well as mobility in the territory.

With regard to mobility and its relationship with the virus, this paper proposes a cognitive framework based on the systems approach to analyze the contagion phenomenon under the concept of urban dynamics. From this basic scheme, we can frame the analysis of the pandemic phenomenon caused by the virus COVID SARSCOV 2 and its relationship to factors associated with the mobility of the population. According to the results of the correlation model, independently of the other health, social and economic factors involved, limitations on mobility should be part of a governmental strategy toward a reduction and control of the pandemic. Since there is a direct relationship between the characteristics of the land use and transportation means (Jiménez, 1996), it is sustained here that this is a variable to be considered in any effective strategy to combat the pandemic. Although the criterion of limiting movement undermines the relevance of the paradigm of freedom, post-pandemic urban-architectural design will have to achieve the objectives of coexistence safe warding human life.

ANNEX 1.

TABLE 1. POPULATION, COVID CASES, AND PERSON TRIPS IN THE METROPOLITAN AREA OF MEXICO CITY

A	B	C	D	E	F	G	I	J
CODE NUMBER	BOROUGH/MUNICIPALITY	POPULATION (1)*	COVID CASES (2)*	TOTAL TRIPS DAY (3)*	COVID/POP (D/C)	TRIPS/POP (E/C)	ACCUMULATED TRIPS (4)*	ACCUM TRIPS/COVID (I/D)
9 001	Álvaro Obregón	755537	190309	1204403	0.25	1.59	867170160	4557
9 002	Azcapotzalco	408441	74056	788446	0.18	1.93	567681120	7666
9 003	Benito Juárez	433708	51499	1013387	0.12	2.34	729638640	14168
9 004	Coyoacán	621952	77246	1380970	0.12	2.22	994298400	12872
9 005	Cuajimalpa	199809	23878	390054	0.12	1.95	280838880	11761
9 006	Cuauhtémoc	548606	77027	1826222	0.14	3.33	1314879840	17070
9 007	Gustavo A. Madero	1176967	169837	1993800	0.14	1.69	1435536000	8452
9 008	Iztacalco	393821	57501	654580	0.15	1.66	471297600	8196
9 009	Iztapalapa	1815551	207096	2908938	0.11	1.60	2094435360	10113
9 010	La Magdalena Contreras	245147	39272	346719	0.16	1.41	249637680	6357
9 011	Miguel Hidalgo	379624	47198	1082474	0.12	2.85	779381280	16513
9 012	Milpa Alta	139371	30572	216015	0.22	1.55	155530800	5087
9 013	Tláhuac	366586	72341	604801	0.20	1.65	435456720	6020
9 014	Tlalpan	682234	137687	1134110	0.20	1.66	816559200	5931
9 015	Venustiano Carranza	433231	64151	860026	0.15	1.99	619218720	9653
9 016	Xochimilco	418060	76188	681717	0.18	1.63	490836240	6442
15 002	Acolman	171507	2591	240743	0.02	1.40	173334960	66899
15 009	Amecameca	53441	1424	68931	0.03	1.29	49630320	34853
15 010	Apaxco	31898	861	43163	0.03	1.35	31077360	36094
15 011	Atenco	75489	2139	79351	0.03	1.05	57132720	26710
15 013	Atizapán de Zaragoza	523674	16678	755282	0.03	1.44	543803040	32606
15 015	Atlautla	31900	550	39223	0.02	1.23	28240560	51346
15 016	Axapusco	29128	520	22553	0.02	0.77	16238160	31227
15 017	Ayapango	10053	96	5186	0.01	0.52	3733920	38895
15 025	Chalco	400057	24601	531780	0.06	1.33	382881600	15564
15 028	Chiautla	30045	392	20504	0.01	0.68	14762880	37660
15 029	Chicoloapan	200750	5434	264653	0.03	1.32	190550160	35066
15 030	Chiconcuac	27692	355	36209	0.01	1.31	26070480	73438
15 031	Chimalhuacán	705193	18088	920140	0.03	1.30	662500800	36627
15 020	Coacalco de Berriozabal	293444	12119	455286	0.04	1.55	327805920	27049
15 022	Cocotitlán	15107	514	12153	0.03	0.80	8750160	17024
15 023	Coyotepec	40885	1282	49382	0.03	1.21	35555040	27734
15 024	Cuautitlán	178847	9460	256939	0.05	1.44	184996080	19556
15 121	Cuautitlán Izcalli	555163	19285	867716	0.04	1.56	624755520	32396
15 033	Ecatepec de Morelos	1645352	75194	2494930	0.05	1.52	1796349600	23890
15 034	Ecatzingo	10827	126	11284	0.01	1.04	8124480	64480
15 035	Huehuetoca	163244	4129	159110	0.03	0.97	114559200	27745
15 036	Hueypoxtla	46757	398	60596	0.01	1.30	43629120	109621
15 037	Huixquilucan	284965	9561	264026	0.03	0.93	190098720	19883
15 038	Isidro Fabela	11929	198	4718	0.02	0.40	3396960	17156
15 039	Ixtapaluca	542211	19953	761214	0.04	1.40	548074080	27468
15 044	Jaltenco	28217	433	41212	0.02	1.46	29672640	68528
15 046	Jilotzingo	19877	663	9710	0.03	0.49	6991200	10545
15 050	Juchitepec	27116	693	30223	0.03	1.11	21760560	31401
15 070	La Paz	304088	9577	424373	0.03	1.40	305548560	31904
15 053	Melchor Ocampo	61220	1655	70812	0.03	1.16	50984640	30806
15 057	Naucalpan de Juárez	834434	42598	1256682	0.05	1.51	904811040	21241
15 059	Nextlalpan	57082	578	43322	0.01	0.76	31191840	53965
15 058	Nezahualcóyotl	1077208	58716	1643691	0.06	1.53	1183457520	20156
15 060	Nicolás Romero	430601	15569	498426	0.04	1.16	358866720	23050

A	B	C	D	E	F	G	I	J
CODE NUMBER	BOROUGH/MUNICIPALITY	POPULATION (1)*	COVID CASES (2)*	TOTAL TRIPS DAY (3)*	COVID/POP (D/C)	TRIPS/POP (E/C)	ACCUMULATED TRIPS (4)*	ACCUM TRIPS/COVID (I/D)
15 061	Nopaltepec	10351	191	5141	0.02	0.50	3701520	19380
15 065	Otumba	36331	608	36161	0.02	1.00	26035920	42822
15 068	Ozumba	30785	1014	37660	0.03	1.22	27115200	26741
15 069	Papalotla	4862	62	5415	0.01	1.11	3898800	62884
15 075	San Mart¡n de las Pirámides	29182	511	20009	0.02	0.69	14406480	28193
15 081	Tecámac	547503	13661	602997	0.03	1.10	434157840	31781
15 083	Temamatla	14130	1922	9645	0.14	0.68	6944400	3613
15 084	Temascalapa	43593	463	29912	0.01	0.69	21536640	46515
15 089	Tenango del Aire	11359	262	7373	0.02	0.65	5308560	20262
15 091	Teoloyucan	65459	1969	75288	0.03	1.15	54207360	27530
15 092	Teotihucán	58507	1545	97913	0.03	1.67	70497360	45629
15 093	Tepetlaoxtoc	32564	342	18241	0.01	0.56	13133520	38402
15 094	Tepetlixpa	20500	436	28974	0.02	1.41	20861280	47847
15 095	Tepotzotlán	103696	1735	129881	0.02	1.25	93514320	53899
15 096	Tequixquiac	39489	602	52491	0.02	1.33	37793520	62780
15 099	Texcoco	277562	7639	404136	0.03	1.46	290977920	38091
15 100	Tezoyuca	47044	1763	54270	0.04	1.15	39074400	22164
15 103	Tlalmanalco	49196	2731	52758	0.06	1.07	37985760	13909
15 104	Tlalnepantla de Baz	672202	42299	1013799	0.06	1.51	729935280	17257
15 125	Tonanitla	14883	146	12934	0.01	0.87	9312480	63784
15 108	Tultepec	157645	4671	139869	0.03	0.89	100705680	21560
15 109	Tultitlán	516341	16897	791984	0.03	1.53	570228480	33747
15 122	Valle de Chalco Solidaridad	391731	10497	524737	0.03	1.34	377810640	35992
15 112	Villa del Carbón	51498	350	19067	0.01	0.37	13728240	39224
	TOTAL URBAN AREA	21164459	1864604	33700840	0.09	1.59	24264604800	13013

SOURCES:
(1) INEGI. Censo de Poblaci¢n y Vivienda 2020.
https://www.inegi.org.mx/programas/ccpv/2020/default.html#Datos_abiertos. (Access april 5, 2022)
(2) COVID cases. https://datos.covid-19.conacyt.mx/#DownZCSV (Access april 24, 2022)
(3) INEGI Encuesta Origen-Destino en hogares de la Zona Metropolitana del Valle de México (eod, 2017). (Access april 15, 2022)
(4) The period considered for the computations goes from 26/02/2020 to 24/04/2022.For the purpose of computations a total of 69 days are discounted from the 789 days that have passed since the beginning the pandemic in Mexico. That figure comes from a 50 percent reduction of total trips on weekends for a final ammount of 720 days.

ANNEX 2.

TABLE 2. CORRELATION MATRIX

	POPULATION (1)	COVID CASES (2)	TOTAL TRIPS/DAY (3)	COVID/POP (D/C)	TRIPS/PERS/ DAY (E/C)	COV/TRIPS (D/E)
POPULATION (1)	1					
COVID CASES (2)	0.790157217	1				
TOTAL TRIPS/DAY (3)	0.967139852	0.82859161	1			
COVID/POP (D/C)	0.406795536	0.75223376	0.49069174	1		
TRIPS/PERS/DAY (E/C)	0.459444782	0.50842805	0.61403023	0.57126046	1	
COV/TRIPS (D/E)	0.254644311	0.58458961	0.28253019	0.87856792	0.20624283	1

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