Use of Physics of Decision to assess how COVID-19 impacted air pollution

Camelia BELLEPEAU
IMT Mines Albi
camelia.bellepeau@mines-albi.fr

Hugo BERGERE
IMT Mines Albi
hugo.bergere@mines-albi.fr

Corentin THEVENET
IMT Mines Albi
corentin.thevenet@mines-albi.fr

Nafe MORADKHANI
IMT Mines Albi
nafe.moradkhani@mines-albi.fr

Thibaut CERABONA
IMT Mines Albi
thibaut.cerabona@mines-albi.fr

Frederick BENABEN
IMT Mines Albi
frederick.benaben@mines-albi.fr

ABSTRACT

This article focuses on the question of the impact of the COVID-19 crisis on air pollution. The chosen approach is based on the principle of "Physics of Decision" (POD), which considers: (i) the performance of a system as a physical trajectory within the framework of its performance indicators, (ii) risks or opportunities (potentialities) as forces that may deviate that trajectory, and (iii) benefits or damages (actualities) as concrete deviations of the performance trajectory. The daily data about the air pollution in Paris area (France) has been gathered for eight years (2014-2021) and three main performance indicators have been chosen. Then, the performance trajectory of each year has been plotted and the expected trajectories of 2020 and 2021 have been guessed from the previous ones. The deviation between the expected and actual trajectories of 2020 and 2021 have been assessed, and using physics and motion laws, evaluated as a deviation force.

Keywords

risk, opportunity, physics of decision, COVID-19, air pollution, performance management, decision support.

INTRODUCTION

It has been often mentioned throughout public and social media that the COVID-19 crisis, and especially the mitigation measures of 2020 and 2021 (especially lockdown and teleworking) have had a strong impact on air pollution mainly by reducing traffic. The strict confinement applied in France between March 17, 2020, and May 11, 2020, could be considered as a full-sized experiment to check if a drastic reduction of car traffic could have a significant effect on some air pollution indicators. This strict lockdown has been defined according to the following rules. French citizens can leave their homes only for the following reasons:

- go to work (if telecommuting is not possible)
- make essential purchases in establishments where the activity is authorized (mainly grocery stores)
- go to the pharmacy or to the doctor's office, if remote consultation is impossible and cannot be postponed
- physical activity within a maximum radius of one kilometer from home (no more than one hour per day)
- go to a judicial or administrative summons
- participate in a mission of general interest upon request of the administrative authority
- a compelling family reason for assistance to vulnerable people or the care of children

It is noticeable that there have been two other lockdowns in France (October 30, 2020, to December 15, 2020, and April 3, 2021, to May 3, 2021) but these two lockdowns have been less drastic (schools and universities have not gone 100% remote for any levels, contrary to the first confinement).

Consequently, the objective of this article is to study the actual impact of lockdown on the air quality of Paris

(France). The question of air pollution is indisputably a main component of global warming and the environmental crisis that mankind is currently facing. Consequently, this article aims at contributing to studying **how much a strong policy measure as a general lockdown impacts air pollution in a major city like Paris**. That research question is besides addressed from an original angle: Based on the selection of some significant air pollution indicators this article presents the study of the impact of the first confinement according to the *Physics of Decision* (POD) principles. The initial idea is to model the actual air pollution as a yearly physical trajectory within the framework of these air pollution indicators. This model of air pollution trajectory can then be studied using the physical principles of motion. The final objective is to evaluate the impact of the studied event (the first confinement in France) as a physical force deviating the air quality trajectory.

Consequently, this article is structured as follows: The next section is dedicated to select the air pollution indicators that are relevant considering (i) their criticality with regards to air pollution, and (ii) their susceptibility to traffic. The following sections presents the POD approach of the study, the obtained trajectories and the "confinement force" calculated from these trajectories. Finally, a conclusion discusses the results and the avenues that can be foreseen from this work.

AIR POLLUTION INDICATORS

Obviously, there are a lot of air pollution indicators that are currently assessed and studied to supervise the actual quality of the air. For the purpose of this article, two main criteria have been defined to select which indicators should be chosen:

- The first criterion concerns the criticality of the indicator in relation to overall air quality. This means that the air pollution indicators to be selected must be of significant importance to the global air quality assessment.
- The second criterion concerns the sensitivity of the indicator with respect to traffic (as this article assumes that the confinement primarily and drastically reduced car traffic).

To deal with these criteria, the European Standards have been considered. Namely, the NEC-2[1] directive has been considered as the main reference. That directive actually defines a list of polluting components that must be assessed, controlled and for which some clear objectives are being defined annually[2].

Based on that directive, some public agencies do control the air quality and report about it. For instance, from Le Moullec and Meleux (2020), it can be observed that out of twelve indicators, five are not reaching the objectives of the previously mentioned directive. The following Table 1 presents these results:

Table 1. French Air Quality

Polluting element	SO_2	NO_2	O_3	PM_{10}	$PM_{2.5}$	CO	C_6H_6	As	Cd	Ni	Pb	B[a]P
Respecting the NEC-2 Directive	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	No	Yes	No
Number of major cities exceeding in 2019	0	9	49	2	0	0	0	0	0	1	0	1

Considering the first criteria, (Le Moullec and Meleux, 2020) defines the "four most emblematic pollutants", namely NO_2, O_3, $PM_{2.5}$ and PM_{10} (both PM_x being particles indicators). Following that vision and in order to match the first criteria, the observed air quality indicators should be extracted from these four.

Considering the second criteria, it can be extracted from (Le Moullec and Meleux, 2020) that the main cause of NO_2 emission in the air is the transport sector at about 63%, as it comes mostly from combustion processes. The main causes of PM_{10} and $PM_{2.5}$ emissions to air are the residential/tertiary sector (32% and 51% respectively) and industry (28% and 20% respectively). Traffic and transport sector also impact lightly PM_{10} and $PM_{2.5}$ emissions (7% and 9% respectively), or even more (16% and 19%) from (Aichi and Husson, 2015). However, there is no primary sector responsible for the emission of O_3 into the atmosphere because O_3 has no direct source in the atmosphere, it is an exclusively secondary pollutant which is formed by solar radiation and complex chemical reactions between different pollutants, in particular NO_x and volatile organic compounds (Bruxelles, 2016). According to these elements and in order to match the second criteria, NO_2 should clearly be one of the selected air quality indicators (it undoubtedly matches all criteria). Regarding O_3, $PM_{2.5}$ and PM_{10} it is not obvious to make a choice. O_3, seems critical and far from being under control, thus it is significant, however, even if it is indirectly linked to traffic, there is no first order connection. $PM_{2.5}$ seems to be under control and is lightly but still

[1] The NEC-2 directive: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016L2284 (last acceded January 24th 2022).

[2] The expectations and results for France are available here: https://www.citepa.org/fr/politique-polluants/ (last acceded January 24th 2022).

significantly depending on traffic, while PM_{10} even if a slightly failing indicator is less depending on traffic.

Thus, to adjust the choice of the right air quality indicators, the progress of these indicators should also be considered. The following Figure 1 illustrates their evolution:

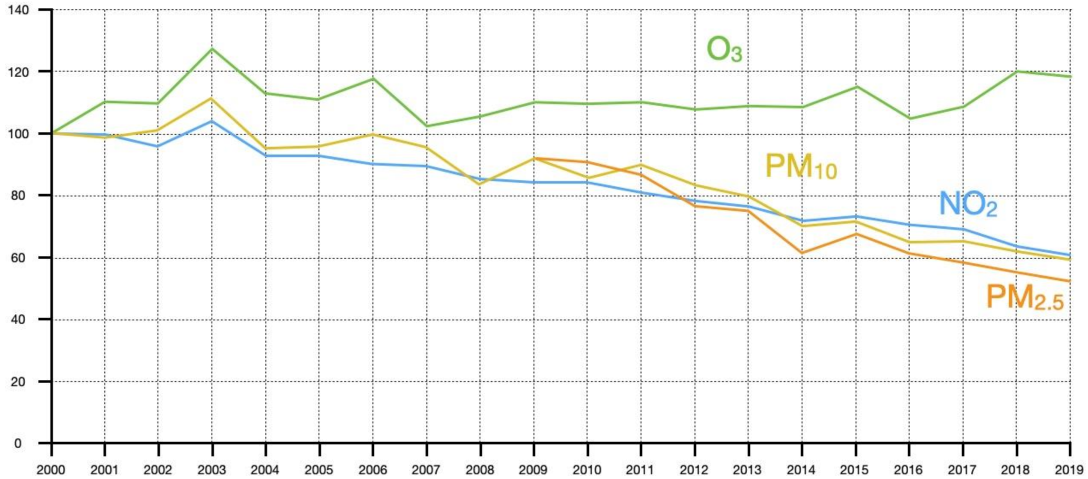

Figure 1. temporal progression of the main indicators – from (Le Moullec and Meleux, 2020).

From these last elements, it seems $PM_{2.5}$ and PM_{10} have a very close trend. It is also obvious that O_3 remains a very problematic indicator. As a consequence, the following of this article will focus on **NO_2** (as stated earlier), **O_3** (due to its criticality), and **$PM_{2.5}$** (as the PM indicators depending the most on traffic). Nevertheless, it can be predicted that NO_2 should be the most sensible indicators, $PM_{2,5}$ probably slightly sensitive, while the behavior of O_3 cannot be anticipated.

One additional comment: one may wonder what the results would have been if the order of consideration of the two criteria had been reversed (selecting first the indicators most depending on traffic, then those with the greatest impact on air quality). This would not have been the right way to proceed because it is important to keep in mind that the expected result is a deviation force, so the first criterion clearly has priority over the second. Doing the opposite would result in calculating a potentially very sensitive but of second or third order force on how the trajectory is defined.

PHYSICS OF DECISION APPLIED TO AIR POLLUTION

The data about the three selected criteria (NO_2, O_3, $PM_{2.5}$) has been collected from official public sources[3] on the seven years covering the period 2014 to 2020. The following Figure 2 illustrates the annual evolutions of the three air quality indicators in 2014 and in 2020 (the other years are available but not presented due to space limit).

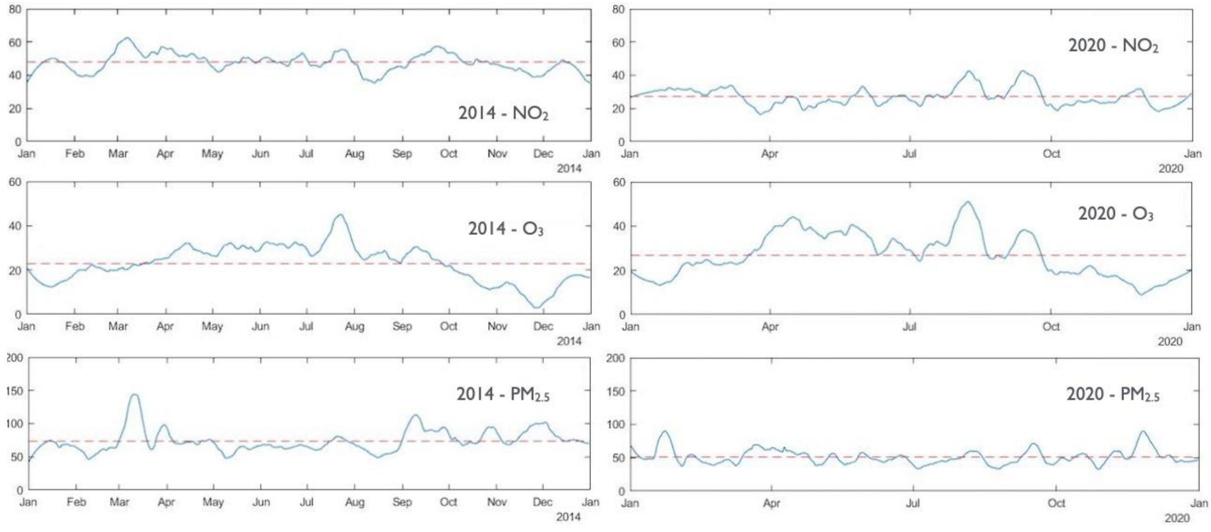

Figure 2. Annual evolution of the three air quality indicators in 2014 and 2020.

[3] https://aqicn.org/city/paris/

Air Quality Trajectories

From this data, the objective is to apply the principles of *Physics of Decision* (POD) as presented in (Benaben, *et al*. 2020) and illustrated through a simulation example in (Moradkhani, *et al. 2021)*. In this context, yearly air quality is represented as a trajectory within the framework composed with three dimensions (NO_2, O_3, $PM_{2.5}$). The dots that are connected by this trajectory represent individually an instant of the considered year for which the measurements of the three indicators (NO_2, O_3, $PM_{2.5}$) are used as coordinates.

Consequently, Figure 3 represents exactly the data gathered from the public sources presented on Figure 2 about air quality in Paris. Each colored trajectory shows a year, and each point is a triplet of measurements of the three selected indicators. We can see on Figure 3 the air quality trajectories of the pre-pandemic period (2015-2019) on the left part and the air quality trajectories of the pandemic period (2020-2021) on the right part.

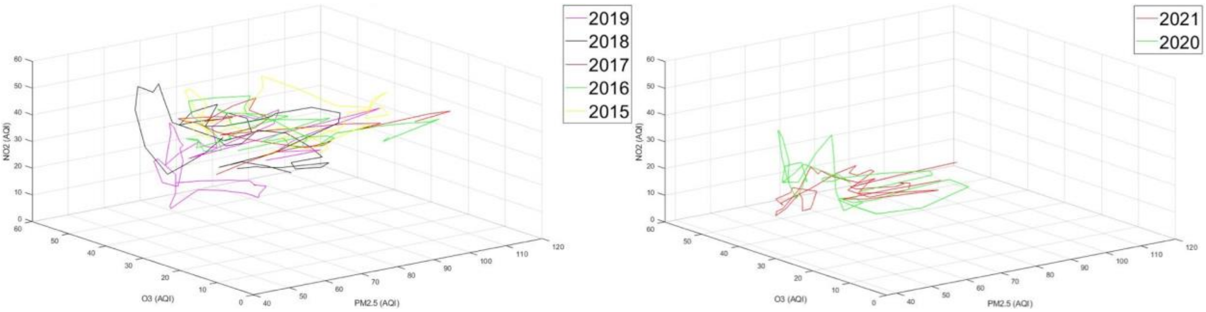

Figure 3. Comparing the 3D trajectories of 2020-2021 (right) to 2015-2019 (left).

Even if it seems that the trajectories of the pandemic period looks less dispersed and closer to the origin (0, 0, 0) than the trajectories of the pre-pandemic period, this can't be considered as a tangible results, especially considered the obvious declining trends of Figure 1. However, Figure 4 presents the 2D projections of the trajectories of Figure 3, and thus provides a more significant visual about the decline during the pandemic period.

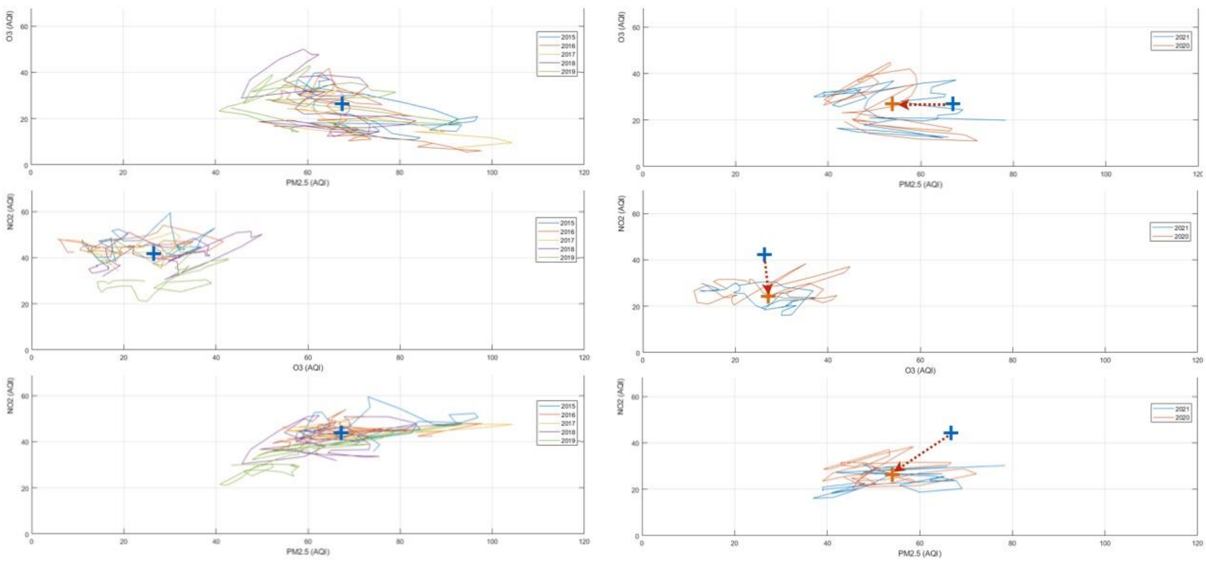

Figure 4. Comparing the 2D trajectories of 2015-2019 (left) and 2020-2021 (right).

The apparent movement that can be observed in the 2D representations of Figure 4 (relative displacements represented by the red dotted arrows between the blue crosses representing the pre-pandemic centers of gravity and the orange crosses representing the centers of gravity during the pandemic) can of course be explained by the decreasing trend observed in Figure 2. Nonetheless, the objective of the following subsection is to investigate whether this trend is the only responsible for the decrease, or if there might be an additional decreasing factor that could be attributed to the confinement.

This will be observed by strictly considering these trajectories as motion trajectories and by applying some physics principles. Basically, the ambition from this point is to try to distinguish the "natural" decreasing trend (due to the efforts to respect the NEC-2 directive) and a potential *confinement force* that could explain the deviation of the pandemic period trajectories.

Seeking for a Confinement Deviation Force

This subsection essentially focuses on 2020. The air quality trajectory of 2020 is shown on Figure 5 which presents the full trajectory and specifically the confinement period (orange area on Figure 5) from a kinetics perspective.

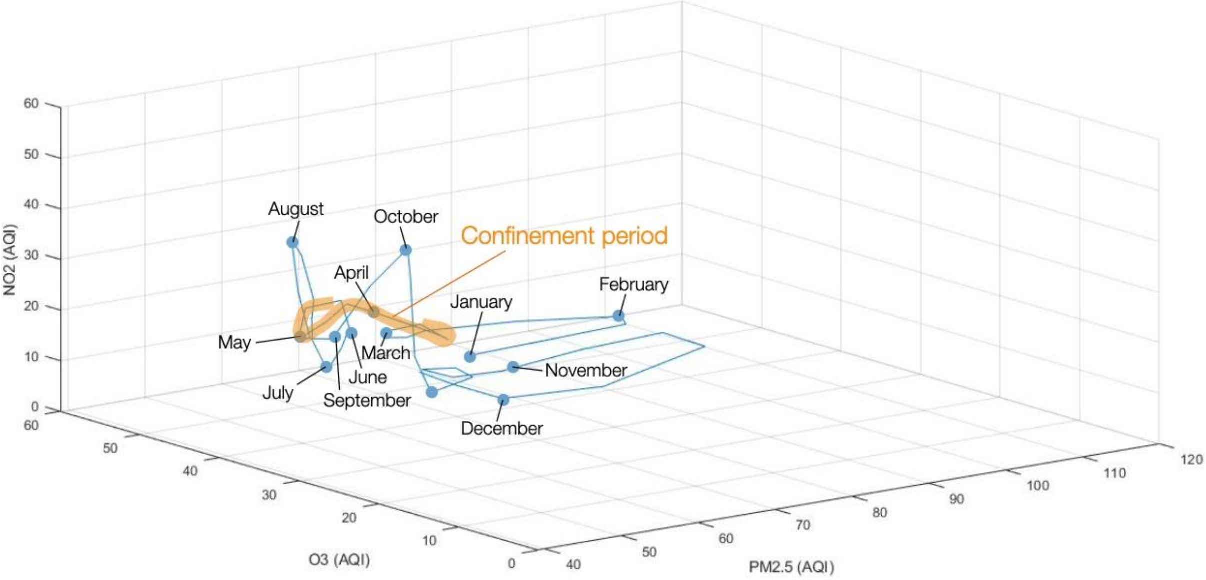

Figure 5. Air quality trajectory for 2020.

For that purpose, Newton's second law of motion will be used. This law claims that *the acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object*. This law is usually formulated as:

$$\mathbf{a = F_{net} / m \Leftrightarrow F_{net} = a.m} \qquad (1)$$

In the current case, considering that there is a trajectory with 3D coordinated representing the position of the object "air quality", it is easy to get the speed (dx/dt, dy/dt, dz/dt), namely (dO_3/dt, $dPM_{2.5}/dt$, dNO_2/dt). Then, acceleration can be obtained as (d^2x/dt^2, d^2y/dt^2, d^2z/dt^2), namely (d^2O_3/dt^2, $d^2PM_{2.5}/dt^2$, d^2NO_2/dt^2). As the literal equation of the 2020 air quality trajectory is not available, the local speed and acceleration are calculated as:

$$\mathbf{Speed = [(x(t)-x(t+\delta t))/\delta t,\ (y(t)-y(t+\delta t))/\delta t,\ (z(t)-z(t+\delta t))/\delta t] = [s_x(t), s_y(t), s_z(t)]} \qquad (2)$$

$$\mathbf{Acceleration = [(s_x(t)-s_x(t+\delta t))/\delta t,\ (s_y(t)-s_y(t+\delta t))/\delta t,\ (s_z(t)-s_z(t+\delta t))/\delta t] = [a_x(t), a_y(t), a_z(t)]} \qquad (3)$$

Considering the mass of the system as "meaningless" here, the main hypothesis that is assumed is the following:

The mass of the considered system when studying the air quality trajectory can be considered as constant.

Then, the remaining question concerns the calculation of the acceleration. As presented in (3), this is a very easy calculation. Figure 6 presents the calculation of the three accelerations for (NO_2, O_3, $PM_{2.5}$).

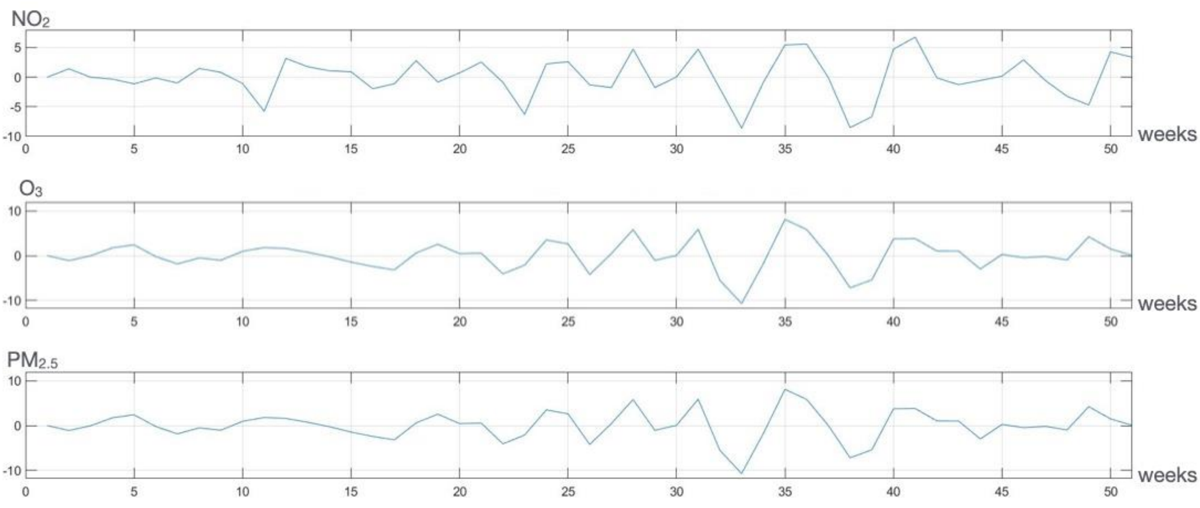

Figure 6. Accelerations of NO_2, O_3, and $PM_{2.5}$ for 2020.

These accelerations are global accelerations, meaning they embed all causes. In this article, it is considered that all causes of accelerations are similar from one year to another, except for 2020 (due to the COVID-19 crisis and especially the confinement). Roughly speaking, there are then the generic causes (mainly the overall political and individual efforts to respects the NEC-2 directive) and the specific cause (the 2020 confinement).

In order to distinguish between these two types of acceleration, the approach is based on the definition of the *theoretically expected trajectory for 2020* (would the COVID-19 crisis not happen). This trajectory can then be used to calculate the theoretically expected accelerations (on the same three dimensions). Then, by subtracting the theoretically expected acceleration from the actually observed acceleration, we obtain an estimate of the portion of the acceleration due to the unexpected event, namely the confinement.

Considering the decreasing trends identified on Figure 1, and the trajectories of Figure 3, this article suggests to use, as *theoretically expected trajectory for 2020* an average calculated from all the values of 2018 and 2019 (each points of the *theoretically expected trajectory for 2020* is based on the average of the values of the same day of 2018 and 2019), to which a decreasing factor is applied according to the trends of Figure 1 (for the three dimensions, the slope observed on Figure 1 is applied to slightly decrease the value according to the trends). On this basis, the following Figure 7 presents the obtained *theoretically expected trajectory for 2020* and its visual comparison with the actual trajectory for 2020.

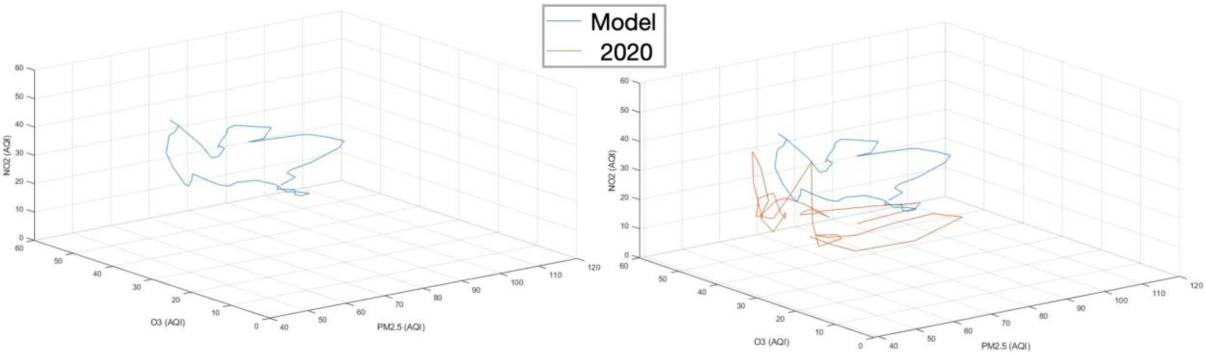

Figure 7. The theoretically expected trajectory for 2020 and the actual trajectory for 2020.

The obtained accelerations for the *theoretically expected trajectory for 2020* with regards with the actual air quality trajectory for 2020 are presented on Figure 8.

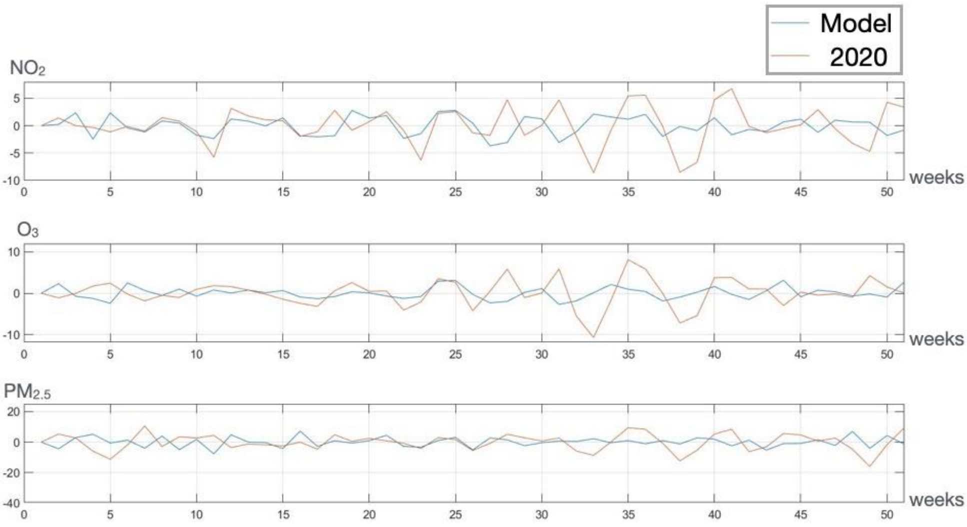

Figure 8. Compared accelerations of actual 2020 and the theoretically expected 2020.

Figure 9 presents the subtracting of the theoretically expected acceleration (*i.e.* the Model's values of acceleration from Figure 8) from the actually observed acceleration (*i.e.* The actual 2020's values from Figure 8). The result is supposed to be the part of the acceleration due to factors that are unexpected. One hypothesis that is made in this work is that these unexpected factors mainly relate to COVID-19 measures.

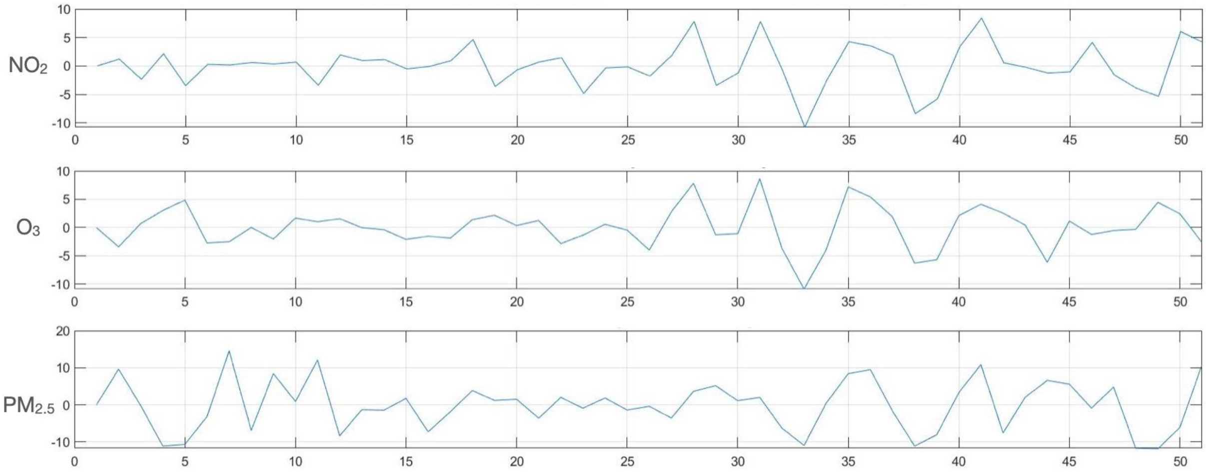

Figure 9. Part of the acceleration that is unexpected.

The following Table 2 presents the 3D vectors associated to these unexpected accelerations (there are actually 365 of these vectors but we chose to present in this table one every three weeks all along the year, and on every two weeks specifically for the confinement period of time).

The first column presents the date of the acceleration, the second, third and fourth column are the actual values of acceleration replicated from Figure 9, and the fifth column gives an indication about the direction of the vector: is it inside the sphere centered on (0, 0, 0) and tangent to the position at that instant (then it improves the air quality) or outside this sphere (then it worsens the air quality).

Table 2. Unexpected acceleration vectors.

	Date	PM25_acceleration	O3_acceleration	NO2_acceleration	Reduce_overall_concentration
1	22-January-2020	-11.0972	3.0160	2.1519	"Yes"
2	12-February-2020	14.5750	-2.5028	0.1654	"No"
3	04-March-2020	0.9163	1.6846	0.6731	"No"
4	18-March-2020	-8.3334	1.5700	1.9519	"Yes"
5	01-April-2020	-1.4258	-0.3682	1.1129	"Yes"
6	15-April-2020	-7.2527	-1.5258	-0.1047	"Yes"
7	29-April-2020	3.8712	1.3951	4.6432	"No"
8	13-May-2020	1.5163	0.3536	-0.6691	"No"
9	27-May-2020	2.0184	-2.8335	1.4374	"No"
10	03-June-2020	-0.8853	-1.3338	-4.8374	"Yes"
11	24-June-2020	-0.3788	-3.9608	-1.7800	"Yes"
12	15-July-2020	5.1782	-1.2520	-3.4188	"No"
13	05-August-2020	-6.2764	-3.6786	-0.8157	"Yes"
14	26-August-2020	8.4387	7.1688	4.2589	"No"
15	16-September-2020	-11.1045	-6.2805	-8.3903	"Yes"
16	07-October-2020	10.8736	4.1078	8.4244	"No"
17	28-October-2020	6.5943	-6.1285	-1.2368	"No"
18	18-November-2020	4.8119	-0.5194	-1.5731	"No"
19	09-December-2020	-6.0602	2.4376	6.0519	"Yes"

Finally, Figure 10 gives a visual representation of these acceleration vectors representing, from the perspective of this work, the deviation force due to the confinement. The values of the fifth column of Table 2 defines the color of the vectors (green for improvement and red for deterioration). It is noticeable that among the nineteen represented vectors, ten are red and nine are green. Besides, during the confinement, three of the four vectors are green (end the red one is really of low magnitude). One final comment is that the second confinement (October 30, 2020, to December 15, 2020) did not create these green vectors (which is consistent with the remarks made in introduction about the difference between the first French confinement and the others).

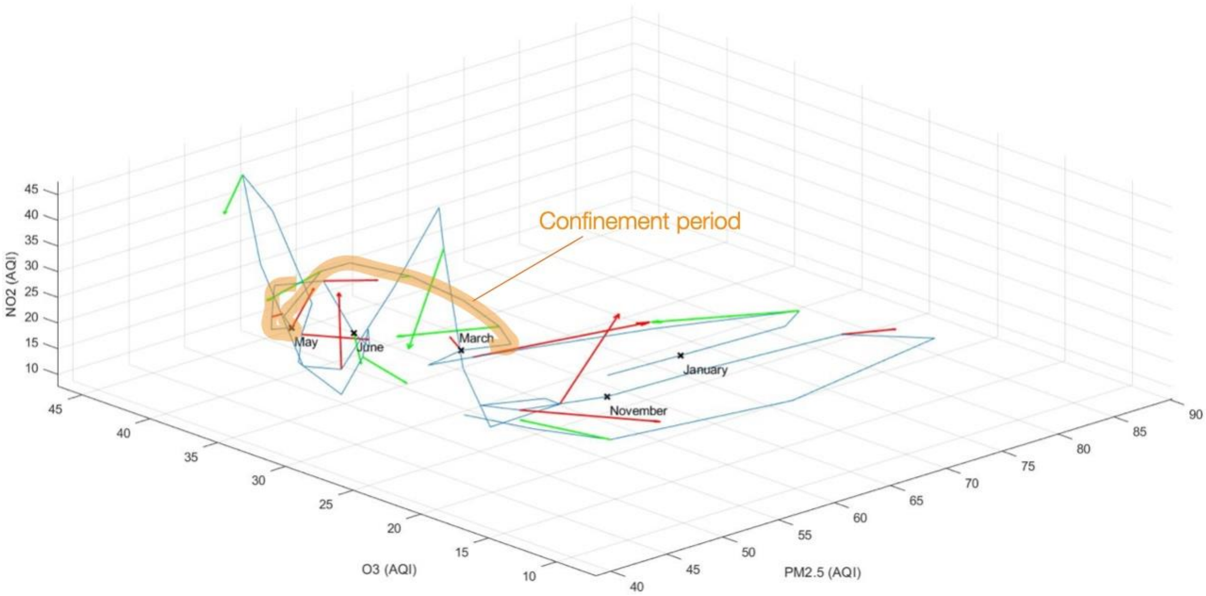

Figure 10. The force vectors due to the confinement according to this study.

CONCLUSION

The main takeaway is that, according to the applied approach, there is a clear impact of the first confinement in France on Paris area's air quality. However, the intensity of this impact does not seem to be of an overwhelming order of magnitude. If we consider the presented approach as trustable, there might be several reasons to these results. First, the impact of car traffic (compared to trucks and others) may finally be minor. Second, the duration of the confinement may also be questionable to have a clear and significant impact on air quality.

From another perspective, the work that has been presented in this article shows that the physics-based approach POD on the one hand provides a visualization paradigm that can open the door to other ways of assessing the actual performance of a system (no need to mention that immersive technology like VR/AR could strongly support that first perspective). On the other hand, this approach also provides a new to consider risks, opportunities, and positive or negative actualities: considering them as actual or potential forces able to deviate the performance trajectory of an observed system may open very disruptive avenues regarding decision making, performance management and more broadly complex system management in unstable environment.

The objective of bridging the gap between management science and physics is not new but still remains ambitious and exciting. If performance spaces could be formally paired with physical spaces, then all laws from motion and kinetics could be inherited and used. Forces could be calculated a priori, summed, eventually studied, and formalized as laws. Calculating the kinetic energy or momentum of a complex system to define which of the identified forces to trigger in order to achieve the targeted performance trajectory, just as a navigator would choose which winds and streams to use to achieve the best race, is a clear perspective of this work.

REFERENCES

Aichi, L. and Husson, J.-F. (2015) Rapport fait au nom de la commission d'enquête sur le coût économique et financier de la pollution de l'air, *Journal Officiel – Édition des Lois et Décrets*, 56-69, Juillet 2015.

Benaben, F., Faugere, L., Montreuil, B., Lauras, M., Moradkhani, N., Cerabona, T., Gou, J., Mu, W. (2021) Instability is the norm! A physics-based theory to navigate among risks and opportunities, *Enterprise Information Systems (EIS),* Taylor&Francis, https://doi.org/10.1080/17517575.2021.1878391.

Bruxelles Environment, (2016) 08. Oxydes d'azote (NOx), *Etat de l'environnement*, 1-17.

Le Moullec, A. and Meleux, F. (2020) Bilan de la qualité de l'air en France en 2019, *public document from Datalab – French Ministry of Ecological Transition*, September 2020. https://www.statistiques.developpement-durable.gouv.fr/sites/default/files/2020-09/datalab_71_bilan_qualite_air_france_2019_septembre2020.pdf

Moradkhani, N., Benaben, F., Montreuil, B., Nazzal, D., Lauras, M., Jeany, J., Faugere, L., (2021) Parametrized SEIR model for performance-based decision support: A case study of COVID-19 epidemic in the state of Georgia (USA). *Proceedings of International System Dynamics Conference SDC 2021*, Chicago, USA.