Strategies for COVID-19 Pandemic Recovery. Applying Engineering Asset Management Principles.

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ABSTRACT

Current COVID-19 pandemic available data for Spain, Andalusia an its eight provinces have been analyzed. Utilizing a model recently published to predict pandemic behavior, confinement measures and their economic impact are analyzed. Applying principles for effective and efficient management of engineering assets, decision-making implications of establishing confinement at national, regional or local (province) level are analyzed. The quarantine time is formulated as a function of the delay in taking confinement measures in the territories. The delay is measured in time since the free expansion in the territory is observed. Results discussions and analysis help to formulate a recommended strategy that is presented in the paper. We aim for: (i) design action plans by local level but(ii) controlled centralized by a unique decision-making center considering by country. Benefits of that strategy are measured in quarantine times beside GDP loss toll recovery. The strategy would be even more convenient when tackling with successive waves of the pandemic, requesting immediate action on local relapses.

Keywords: COVID-19 Recovery, Local Confinement Reduction, COVID-19 Economic Impact, health policy, Engineering Asset Management

Introduction and Proposal

The relative position that an item occupies in a system it's called its level of indenture [1,2]. Engineering systems usually have many such levels, and achieving the required system's performance at a certain expense requires the identification of the most suitable indenture level for management [3].

Before applying this concept to try to improve the COVID-19 recovery strategy, we proof that in complex systems: reaching desired system performance is more expensive when the data, and management of their failures, are handled at higher indenture levels; Cost of strategies to ensure dependability of complex systems increases linearly when the cost of restoring the low-level item increases

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and the higher the indenture level the higher the increase rate; Cost of the strategy grows inversely proportional when dealing with high frequency of these systems' failure, triggering the cost when managing at the higher levels.

This paper focuses on the design and implementation of recovery strategies when the COVID-19 pandemic is underway, applying above mentioned principles. Three factors that could have high impact in the optimization of post-quarantine reactivation decision making are discussed. Based on this scientific analysis, we propose:

1. A local pandemic management indenture level: In Spain, current decision-making (until may 5th) applies to the entire country, simultaneously. We analyzed how applying adapted measures by lower geographical management units (management Indenture Levels) allow optimizing local and global behavior and socio-economic impact faster. Considering the political distribution of Spanish territory, this level could be assimilated to provinces (*provincias*). It is very important to note that sanitary resources allocation in Spain has, historically, a fundamental distribution by provinces. Nevertheless, decision making should be keeping centralized in a unique decision center.
2. Quarantine time local determination: In accordance with the lower indenture level identification, it is possible to assume and predict different quarantine time levels by provinces. For instance, the prediction model used established a recommended quarantine of only 40 days for Huelva, while considering the global a unique decision for Spain (same measure simultaneously) would impose 70 days of quarantine using the same law, which means 40% more confinement than what Huelva really needs. This conclusion can be extended to other provinces where the "hard control measures" were taken before local pandemic free expansion point
3. Early relapses detection: During the recovery phase, once quarantine ends, it is critical to detect potential relapses as soon as possible. A unique method to monitor most important descriptors (not only test but also new infections rates, mobile geolocation data, etc.) that allow detecting local relapses have to be urgently develop. Note again that relapses, in case they happened, will be local, not global by country. So, the relapse control method will be: (i) a unique method, (ii) applied by provinces but with centralized control and unique decision-making center by country. A unique method allows benchmarking between different evolution of different provinces, which is crucial for getting a faster learning curve of decision making.

The indenture level concept

Within the areas of system engineering and asset management, the relative position that an area occupies in a system it's called its level of indenture.

Engineering systems usually have many such levels, which identify or describe the relative complexity of an assembly or function [3] . The "end effect" is a concept used to identify the consequence that a very low level of indenture (usually an identifiable, non-divisible item or its failure mode) has upon the operation, function or status at the highest considered indenture level. The failure mode is the manner in which the item potentially fails to meet or deliver a required function and associated requirements.

When carrying out an economic analysis of the system, the objective of the analysis largely determines the type and the degree of the analysis undertaken. The prerequisite for any economic analysis is reliable and appropriate data. In many occasions in industrial practice, data is not reliable or sufficiently accurate, in sufficient detail, or arranged in a manner which facilitates its use [4].

This paper is about the value of arranging data in the proper manner, to the suitable level of indenture, when trying to optimize system's performance.

Economic impact of low indenture level data and management

The following example is elaborated as a proof of the concept, with the aim of verifying that this concept or idea has practical potential or implication to tackle the resolution of the fundamental problem in the paper.

Assume that we try to reach the highest performance of a system (measured this time in terms of reliability) at the minimum expense in preventive maintenance. What is the less costly preventive plan ensuring high system reliability?

System Level	**Comp. Level**	**Item Level**	**Time to System Failure**	Time to Comp. failure			Time to Item failure				
				TTF C1	TTF C2	TTF C3	TTF C1–X	TTF C1–Y	TTF C2–Z	TTF C2–W	TTF C3–M
S	S – C1	S – C1 – X	100	100			100				
S	S – C2	S – C2 – Z	100		200				200		
S	S – C1	S – C1 – X	100	200			200				
S	S – C2	S – C2 – Z	100		200				200		
S	S – C3	S – C3 – M	100			500					500
S	S – C1	S – C1 – Y	100					600			
S	S – C2	S – C2 – W	100		300					700	
S	S – C1	S – C1– X	100	200			500				
S	S – C3	S – C3 – M	100			400					400
S	S – C2	S – C2 – Z	100		300				600		
S	S – C1	S – C1– X	100	300			300				
S	S – C1	S – C1 – Y	100	100				600			
S	S – C3	S – C3 – M	100			400					400
S	S – C2	S – C2 – W	100		400					700	

Table 1. Time to failure per IL (example with 1 system, 3 components & 5 Items).

The system (S) consists of three components (C1, C2, & C3), each one of them having different items subject to failures (C1-x, C1-y; C1-z, C2-w; & C3-m) causing system to fail as an end effect. The cost to restore a faulty item is known CPM_{Cij} (100 $ for any component i and item j in the case study, see third line in Table 2). The cost of the treatment is, however, different when considering the information available for the different levels of indenture:

- To ensure reliability performance of the system when only *system indenture level* data is available, the analyst would proceed obtaining the minimum time between two consecutive failures of the system (fixed at 100-time units on purpose for this case study, see column 4 in Table 1) and suggesting a PM interval (T_{mp}) shorter than that period. The lack of information about the items failures would force the strategy of restoring all system items (at a total cost of $CPM_S = 500$ $) with that frequency (for instance 95-time units in our example). The risk of the system failure would be practically mitigated with at the following maintenance expense (per time unit):

$$\overline{C}_{MPs} = \frac{CPM_S}{T_{mp}} = \frac{500}{95} = 5.3\,\frac{\$}{t.u.}$$

- In case this solution would not meet stakeholders' expectations, the analyst could lower the IL and work at the *component indenture level*, disaggregating the time to failure (TTF) information by component, calculating for each one of them the minimum time until the next failure (see columns 5, 6 & 7 in Table 1). If this information is now available to the analyst, the strategy would change to carry out PMs per component at shorter times as PM intervals ($T_{mpc1}, T_{mpc2}, T_{mpc3}$). In this case system reliability would be reached with the following maintenance cost per time unit:

$$\overline{C}_{MPc} = \frac{CMP_{c1}}{T_{mpc1}} + \frac{CMP_{c2}}{T_{mpc2}} + \frac{CMP_{c3}}{T_{mpc3}} = \frac{200}{95} + \frac{200}{195} + \frac{100}{395} = 3{,}38\,\frac{\$}{t.u.}$$

- Again, this solution could not be sufficient enough to meet cost expectations and the analyst could work at the lowest IL, disaggregating the information by item failure mode (at an extra cost in systems and data processing). Following the same procedure (see columns 8-12 in Table 1), the risk of the system failure would be practically mitigated to the following expense:

$$\overline{C}_{MPfm} = \frac{CMP_x}{T_{mpx}} + \frac{CMP_y}{T_{mpy}} + \frac{CMP_z}{T_{mpw}} + \frac{CMP_W}{T_{mpw}} + \frac{CMP_m}{T_{mpm}} = \\ = \frac{100}{95} + \frac{100}{595} + \frac{100}{195} + \frac{100}{695} + \frac{100}{395} = 2{,}13\,\frac{\$}{t.u.}$$

	System Level	Component Level			Item level				
		TTF C1	TTF C2	TTF C3	TTF C1–X	TTF C1–Y	TTF C2–Z	TTF C2–W	TTF C3–M
MTTF (time)	100,0	180,0	280,0	433,3	275,0	600,0	333,3	700,0	433,3
Minimum TTF (time)	100,0	100,0	200,0	400,0	100,0	600,0	200,0	700,0	400,0
PM activity cost ($)	500,0	200,0	200,0	100,0	100,0	100,0	100,0	100,0	100,0
PM Interval (time)	95,0	95,0	195,0	395,0	95,0	595,0	195,0	695,0	395,0
Average Cost ($/t)	5,26	2,11	1,03	0,25	1,05	0,17	0,51	0,14	0,25
Strategy PM cost ($/t)	5,26	3,38			2,13				

Table 2. Summary of the economic analysis results per management indenture level.

Table 2 shows the results of the analysis that, that has been then repeated increasing the PM cost of the item failure modes (for all items at the same time, from 10 to 100 $) and also increasing the frequency of the system failure (from 100 to 10 time units). These experiment results are presented in Figures 1.

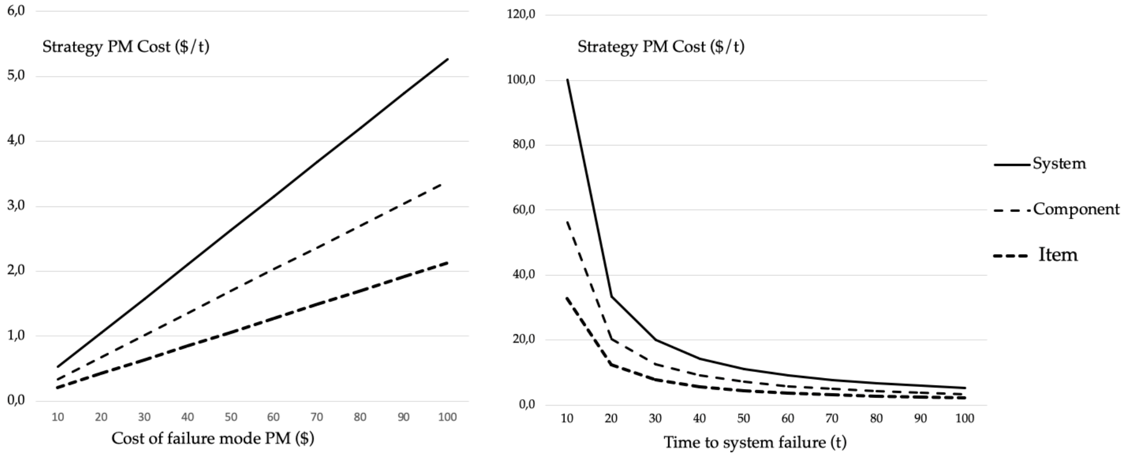

Figure 1. Economic analysis per management IL (System, Component and Item).

Conclusions of the economic analysis per IL are rather interesting:

- The cost of reaching desired system performance is more expensive when the data and management of the failure mode is made at a higher indenture level.
- The cost of the maintenance strategy increases linearly when the item PM cost increases. The higher the indenture level the higher the increase rate.
- The cost of the strategy grows inversely proportional with the increase in the frequency of system failure. High frequencies trigger cost at the system level.
- The higher performance of the system the higher expected PM frequency and the higher the expected cost.

Notice that, when required system's performance is very high because of the severity of its functional loss, the strategy should focus on providing systems for the data extraction, at the lowest cost, for the lowest indenture level, and to manage maintenance activities at that level. Also, additional plans to monitor the item and implement condition base maintenance (CBM) as soon as technically feasible and economically admissible should be developed.

Applying the learnings to the pandemic strategy

In this work it is proposed to use the above referred engineering and asset management domain-specific knowledge, by analogy, to design a compelling strategy for recovering from COVID-19 pandemic. It is emphasized the utilization of this knowledge in the context of policy making, to face the pandemic consequences at different levels of government (management levels) of the socio-political system structure.

A creative free association technique is used, to provide clarity or to identify hidden similarities between two ideas. During this process ideas, will be subject to screening, to identify those which satisfy the following requirements [5]:

- It is feasible to implement
- It is less costly that the present observed policy design
- It will satisfy the system needs

The ideas surviving the initial screening will then be rated according to their ability to satisfy the above-mentioned criteria. The advantages and disadvantages of each idea will then be noted. Preliminary cost estimates will be developed for the most promising ideas (technically and economically).

COVID-19 Pandemic velocity and severity

The velocity of an epidemic — the speed with which an epidemic spread through a community — is a function of the basic reproductive rate for the disease in question (estimates suggest that the reproductive rate for most strains of COVID-19 is more than 4) and how long it takes for infected individuals to infect others (generation time). COVID-19 is highly infectious with a long generation time — that is, the duration of the latent (around 5 days) and infectious periods (around 20 days).

The cardinal determinants of the public health response to a pandemic will be its severity, as defined by the ability of the pandemic virus to cause severe morbidity and mortality, especially when that happens in otherwise low-risk populations, and with no effective vaccine nor antiviral medications available [6]. The severity of illness caused by a strain of COVID-19 is resulting to be very high, and pandemic potential is continually under monitoring and analysis, allowing to refine initial assessments.

With the pandemic becoming severe, groups receiving priority access to medical countermeasures, at high risk of serious illness and death , reflect the need to ensure the medical supplies, maintaining critical infrastructure and security functions. In a less severe scenario, less concerned about infrastructure, public health authorities may, for many patients, opt for home care, with or without isolation. In this way, the costs and benefits of infection control measures would be calculated differently.

Response strategy and containment

The main goals of containing the disease after the pandemic are [6]:

- Delay the spread of the disease and therefore prevent the appearance of outbreaks in other populations;
- Decrease the rate of clinical attack in affected populations;
- Flatten the infected curve as a function of time, avoiding saturation of hospitals;
- Minimize hospitalizations and death as much as possible.

In the case of COVID-19 pandemic, the absence of accurate diagnostic testing made the identification of the first cases in the different communities impossible (with some few exceptions). Therefore, severe disease containment and infection control measures became a critical action.

It seems logical to think that the decisions of when to carry out the containment of the pandemic in a population and how to implement the measures associated with this containment, will impose significant costs on the affected communities. Therefore, determining the optimal moment of containment will be a very important and politically relevant decision. At the same time, that may become very difficult problem to solve due to the lack of quantitative data on the benefits and effectiveness that arise from earlier containment.

Many national pandemic strategies recognize that preparing for and responding to a pandemic cannot be viewed as a purely national responsibility, and that a system of plans at all levels of government, and in all sectors, must be integrated to address the pandemic threat.

Although a pandemic can affect hundreds populations at the same time, each population will experience the pandemic as a local event and could rapidly contain the localized outbreaks domestically. Therefore, communities must develop a credible pandemic preparedness plans to respond to an outbreak within their own jurisdictions.

Of course, containment actions must be coordinated at a national level, but decisions to implement disease containment measures are proposed to be made on a community-by-community basis, with the National Governments providing technical support and guidance to regions and local officials on the efficacy of various social distancing measures, the manner in which they can be implemented, and strategies to mitigate unintended consequences [7].

In order to carry out the analysis and modeling of the COVID-19 pandemic, knowledge about the biology and transmission patterns of the virus and about the impact of containment strategies must be manageable in real time.

Selected model for quarantine confinement determination

In this paper we propose to follow Gañán-Calvo et al. [8] approach, which allows to model the pandemic “Confirmed" C(t) and “Deaths" D(t) using only time as independent variable, and supports the existence of a power-law in this variable. In their proposal, they concentrate in two non-dimensional parameters both: (i) the fundamental properties that the medium exposes to the action of the virus, and (ii) a simple model for the early behavior of the system prior to the asymptotic regime.

More precisely, a self-similar simple universal time-power law of the type $\varphi = \tau^{\alpha}$ is used to predict the behavior of COVID-19 pandemic before containment measures are enacted, where τ is the appropriate non-dimensional time since the onset of the free expansion, α is a fitting parameter with a value $\alpha = 3.75$ and φ the non-dimensional time descriptor of the infected population and mortality.

The predictors are defined as $\varphi_C = C/C_C$ or $\varphi_D = D/(m \cdot C_C)$ for confirmed and deaths respectively, where $C_c = 1.2 \times 10^4$ is a characteristic size of the pandemic infectious population, and m is an average early mortality descriptor observed with respect to confirmed cases, which may depend on the population structure and health system (showing homogeneity around the value m = 0:15, regardless the country).

Their more relevant result to this paper is the total confinement quarantine that they recommend after the first 100 cases of any unknown infection produced by a coronavirus are reported. They suggest to take a quarantine of the order of two times the period given by

$$T_Q = (t_{90\%} - t_c) = T_L \times (1 + (t_m - t_c)) \tag{1}$$

Where t_m is the day when measures are enacted, t_c the time where the expansion takes place and $t_{90\%}$is the time when the 90% of the total maximum expected people infected is reached, specific for each geographic region. COVID-19 exhibits a characteristic infection time TL = 20.1 days according to measurements from the evolution of the pandemic in China. In the case that confinement is not yet in place, and the pandemic is in free expansion, quarantine measures must be taken immediately, and the death toll and quarantine period can be estimated using $\varphi_D(t)$ results once t_m is fixed.

Scenario definition, data and confinement time calculation

The model has been applied to do the economic impact analysis of COVID-19 pandemic in Andalusia, defining the following three scenarios:

- Scenario 1. The management Indenture Level is Spain. Confinement period is calculated with data aggregated at a national level and confinement applies to the entire country, regions and provinces, simultaneously.
- Scenario 2. The management Indenture Level is Andalusia. Quarantine time is obtained with data aggregated at regional level and confinement applies to all region's provinces, simultaneously.
- Scenario 3. The management Indenture Level is each province. Quarantine time is obtained with data of the province and confinement applies to each province, separately.

Regardless the scenario, it seems convenient to keep decision-making centralized, in a unique decision center, at national level. Data for the country, region and provinces is presented in Table 3, which includes the model input data and results for each government indenture level.

	Date	t_c (days)	$t_m - t_c$ (days)	T_Q (days)
Spain	25-feb	0	18	76
Andalusia	4-mar	8	6	52
Almería	8-mar	12	2	44
Cádiz	10-mar	14	1	42
Córdoba	12-mar	16	2	44
Granada	12-mar	16	2	44
Huelva	16-mar	20	0	40
Jaén	11-mar	15	3	46
Málaga	5-mar	9	5	50
Seville	12-mar	16	2	44

Table 3. Model results presented for three main government levels within Spain.

Economic impact of confinement per scenario

Table 4 shows the list of economic sectors affected by COVID-19 in Andalusia in column 1; an estimated percentage of loss of each sector's contribution to the regional GDP in column 2; and their current GDP contribution (as a percentage of the GDP) in column 3. The data is provided by the Center for Economic Prediction (CEPREDE) on March 23rd 2020.

With this data, we have simulated the three defined scenarios, and results are presented in columns 4, 5 and 6 of Table 4. In view of the results of scenario 1, GDP falls by just under 4.6 points. In Scenario 2, taking the quarantine time of Andalusia instead of Spain, we would obtain an overall reduction in GDP of approximately 3.1 points, which would mean losing 1.45 points of GDP. Finally, calculated the loss of wealth generated in each of the sectors, now considering the estimated quarantine time for each province, the GDP losses would be only 2.7 points, which implies an improvement of 1.87 points compared to scenario 1 and 0.46 points with respect to scenario 2.

Economic Sector	Percentage of monthly loss of the sector	Andalusia Current situation	Andalusia Scenario 1	Andalusia Scenario 2	Andalusia Scenario 3
A. Agribusiness, Cattle industry	-1.4	6.856%	6.613%	6.690%	6.715%
B. Extractive industry	-0.9	0.340%	0.332%	0.335%	0.336%
C. Manufacturing industry	-2.1	7.872%	7.453%	7.586%	7.630%
D. Electricity and gas supply	-0.9	2.267%	2.215%	2.232%	2.237%
E. Water supply; Sanitation	-0.9	1.318%	1.288%	1.298%	1.301%
F. Construction	-0.3	6.281%	6.233%	6.248%	6.253%
G. Wholesale and Retail; Repair	-3	12.312%	11.376%	11.672%	11.758%
H. Transport and storage	-2.7	4.165%	3.881%	3.971%	3.998%
I. Hostelry	-7	7.388%	6.078%	6.492%	6.602%
J. Inf. & Comm. Technologies	0	1.898%	1.898%	1.898%	1.898%
K. Financial and insurance	-1.5	3.194%	3.073%	3.111%	3.122%
L. Real estate activities	-1.5	13.371%	12.863%	13.023%	13.069%
M. Professional, scientific and technical activities	-0.6	3.648%	3.592%	3.610%	3.615%
N. Admin. and auxiliary services	-0.6	3.167%	3.119%	3.134%	3.138%
O. Public admin. and defense	-0.6	7.952%	7.831%	7.869%	7.881%
P. Education	-0.6	6.390%	6.293%	6.324%	6.333%
Q. Health and social services	-0.6	6.902%	6.797%	6.830%	6.840%
R. Artistic and entertainment	-3	1.820%	1.682%	1.725%	1.738%
S. Other services	-1.1	1.953%	1.898%	1.915%	1.920%
T. Household activities	0	0.905%	0.905%	0.905%	0.905%
Total		100.000%	95.421%	96.867%	97.288%
GDP Losses			4.579%	3.133%	2.712%

Table 4. Impact on the current GDP of Andalusia of the different scenarios (Source: CEPREDE, Centre for Economic Prediction (CEPREDE). 23/03/2020.).

In Table 5, results of the tree different scenarios are presented by province. In the last two columns we show potential reductions of the GDP loss toll relative to the first scenario. Considering an estimated value for the Andalusia's GDP around 160,222 M€ (For precise data see [9,10]), the absolute savings in GDP loss toll for would be around $160{,}222\ M€ \times (4.579\% - 2.712\%) = 2{,}991.34$ M€ result of using the estimated quarantine times by province (which supposes an earlier return to economic activity) instead of the estimated quarantine time for the whole country.

	GDP Loss (Scenario 1)	GDP Loss (Scenario 2)	GDP Loss (Scenario 3)	Reduction of GDP loss toll SC3 vs. SC1	Reduction of GDP loss toll SC3 vs. SC2
Andalusia	4,579%	3,133%	2,712%	40,776%	13,441%
Almería	4,745%	3,247%	2,747%	42,105%	15,385%
Cádiz	4,682%	3,203%	2,587%	44,737%	19,231%
Córdoba	4,239%	2,900%	2,454%	42,105%	15,385%
Granada	4,521%	3,093%	2,617%	42,105%	15,385%
Huelva	4,490%	3,072%	2,363%	47,368%	23,077%
Jaen	4,214%	2,883%	2,550%	39,474%	11,538%
Málaga	5,207%	3,563%	3,426%	34,211%	3,846%
Seville	4,176%	2,857%	2,418%	42,105%	15,385%

Table 5. Expected impact on current GDP per region, provinces and scenarios.

Finally, Table 6 contains data for Málaga, the province that would suffer the highest impact of the COVID-15 pandemic.

Economic Sector	Percentage of monthly loss of the sector	Málaga Current situation	Málaga Scenario 1	Málaga Scenario 2	Málaga Scenario 3
A. Agribusiness, Cattle industry	-1,4	2,545%	2,455%	2,484%	2,486%
B. Extractive industry	-0,9	0,080%	0,078%	0,079%	0,079%
C. Manufacturing industry	-2,1	3,242%	3,069%	3,124%	3,128%
D. Electricity and gas supply	-0,9	1,750%	1,710%	1,723%	1,724%
E. Water supply; Sanitation	-0,9	0,971%	0,949%	0,956%	0,956%
F. Construction	-0,3	8,219%	8,156%	8,176%	8,178%
G. Wholesale and Retail; Repair	-3	13,490%	12,465%	12,789%	12,816%
H. Transport and storage	-2,7	3,990%	3,717%	3,803%	3,811%
I. Hostelry	-7	11,964%	9,842%	10,512%	10,568%
J. Inf. & Comm. Technologies	0	2,124%	2,124%	2,124%	2,124%
K. Financial and insurance	-1,5	3,433%	3,303%	3,344%	3,348%
L. Real estate activities	-1,5	16,828%	16,189%	16,390%	16,407%
M. Professional, scientific and technical activities	-0,6	3,470%	3,417%	3,434%	3,435%
N. Admin. and auxiliary services	-0,6	4,216%	4,152%	4,172%	4,174%
O. Public admin. and defense	-0,6	6,169%	6,075%	6,105%	6,107%
P. Education	-0,6	5,480%	5,397%	5,423%	5,426%
Q. Health and social services	-0,6	6,116%	6,023%	6,053%	6,055%
R. Artistic and entertainment	-3	2,194%	2,027%	2,080%	2,084%
S. Other services	-1,1	2,672%	2,597%	2,621%	2,623%
T. Household activities	0	1,046%	1,046%	1,046%	1,046%
Total		100,000%	94,793%	96,437%	96,574%
GDP Loss			5,207%	3,563%	3,426%

Table 6. Expected impact on current GDP of the Málaga province, per scenario.

Conclusions

A simple universal law to model the pandemic dynamics, besides data sets structured according to the administrative/political indenture levels of the country, permitted a much-detailed prediction of the disease behavior.

This knowledge about infection behavior at country, region and provinces level allows a more precise analysis of confinement periods that is always set up to two times the period to reach the 90% of the maximum infected population at confinement, regardless the indenture level considered.

Analysis of the pandemic economic impact is done for three scenarios according to the three possible management indenture levels and related confinement periods. Benefits in terms of GDP loss toll reduction are estimated for each one of the scenarios considered.

Of course, a risk will be taken with the early opening of the confinement. This will require strict control to avoid displacement to confined areas. Likewise, unconfined areas will need to monitor the population for early possible reinfection, situation that could lead to new confinement measures. We suggest this relapse control method to be a unique method, and applied by provinces but with centralized control and unique decision-making center by country.

The same model could even be even extended to municipalities level, which would facilitate the opening of confinement in smaller population areas, opening a certain level of economic activity while maintaining contacts restrictions between released and non-released areas.

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