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Timing analysis of the sanitization process due to the COVID-19 pandemic in an elementary school using simulation

Vianey Michelle Zavala Pérez[1,*], Ricardo Torres Mendoza[2,*]

[1, 2] Faculty of Engineering, UNAM, Ciudad Universitaria, Ciudad de México, 66455, México

[*] Corresponding author. Email address: zavala.michelle@hotmail.com, ricardtm@unam.mx

Abstract

The recent pandemic caused by the COVID-19 virus, forced all educational institutions in the Mexican national territory to close their doors to face-to-face classes during the month of March 2020. It was many months later, when the Ministry of Public Education announced the return to hybrid classes for the 2021-2022 school year. This represented a challenge for schools in this national territory, particularly those from primary level since all institutions must have had biosafety and disinfection protocols in order to receive all their students and safeguard their safety. For this reason, a primary school was chosen for this study and a discrete event simulation was performed; the main objective of the simulation was to analyze the time invested in the different sanitizing stations, as well as the establishment of new stations to choose the best option that can lead to a timely disinfection process that accommodates the total number of students without affecting the planned day-to-day academic activities.

Keywords: School admission, lockdown, COVID-19, simulation

1. Introduction

Basic level education in Mexico consists of three levels: preschool, primary school and middle school (SEP), which in turn are divided into two sectors according to the organization that provides the education: public education (provided by the government) and private education (provided by private educational institutions).

Until 2019, there were 97,553 primary education schools registered in Mexico, of which 88,526 belong to the public sector and 9,027 belong to the private one (INEE, 2019).

In other words, the private sector of primary education represents 9.3% of the total number of schools all over the Mexican territory.

Of the 14,137,862 students enrolled at the primary level, the public sector attends approximately 12,824,766 students, in contrast to the private sector which attends 1,313,096 students at the same level (INEE, 2019).

These statistics show that the most number of students enrolled at the primary level throughout Mexico belongs to the public sector.

On March 23rd, 2020, the Ministry of Health declared a state of emergency in Mexico due to the SARS-CoV-2 pandemic (Ebrad, 2020).

In the declarations of the Ministry of Health, the lockdown of the Mexican population was decreed; stopping all sort of education and occupation activities and all those considered as non-essential.

Undoubtedly, one of the main sectors to be directly affected by the confinement was the Education Sector since the Mexican government established that the

2020-2021 school year would be carried out remotely (from August 2020 until June 2021).

For the subsequent school year, the Secretary of Public Education announced that due to economic and social issues, the return to school activities for basic education institutions would be carried out under a hybrid model scheme as an emerging measure for the progressive reincorporation of students into their schoolwork (Gómez 2021).

This declaration represented a challenge for educational institutions since they had never worked under these conditions. For this reason, it was necessary to figure out new ways to adapt not only their academic strategies but also their facilities and infrastructure to this new reality.

In August 2021, many elementary schools returned to classes in a hybrid modality, but a new problem arose during this return.

Some of the sanitization protocols were observed to be so thorough and extensive that it takes too much time for schools to perform the whole process for all their students and it is thought that it could be having a negative impact on the learning time of students.

2. State of the art

There are many papers related to COVID-19 pandemic sanitization process, however, most of them are about the study and application in the health sector and none of them are focused in the educational sector or specifically in the return to face-to-face classes.

Such is the case of a study made by Andrew Hummel, Awatef Ergai, et al, in which a sterilization room using UVC was designed to completely eliminate the COVID-19 virus in hospitals.

Authors performed an UVC´s spectrum evaluation and simulation of photon exposure and wavelength to design a fluorescent light bulb capable of producing UVC light (Hummel, Ergai, et al; 2022).

In this same sense, authors Kierat, Weronika, et al; performed a similar study in which they used UVC radiation to sterilize face masks for their re-use (Kierat, et al; 2020); as well as a study made by Matteo Lombini, et al, where an optical cavity was designed with the aim of sterilize air using ultraviolet radiation (Lombini, et al; 2021).

Although, given that pandemic and confinement is a relatively current issue, there is not much literature or studies focusing on conducting simulations which guarantee a successful return to face-to-face classes.

Thus, there are some articles that describe some of the effects of distance learning, as well as some studies on how this mode of study has affected students and the necessary measures to return to face-to-face classes.

A comparative study among various regions of Sicilia revealed that schools are a source of spread of COVID-19, since it was reported that infections increased by 2.6% in the two weeks following the opening of schools (Amodio, et al; 2022).

In this regard, the authors Chang, Chien and Malagon-Palacios performed a time series modeling for the schools reopening in both scenarios: following and do not following the sanitary filter process.

All with the aim to identify the increase in COVID-19 infections among the students´ community during the first 21 days of returning to face-to-face classes (Chang, et al; 2022).

Authors performed a retrospective and observational study in which they used a Bayesian Structural Time Series model (BSTS), that is a statistical model used for time series forecasting, inferring causal impact and feature selection (Qiu, Ning, et al; 2018).

Their models were designed to investigate the country-level of COVID-19 by comparing the daily cases of COVID-19 after school reopening, to the BSTS time series that respond to the predictive daily cases if not reopening during the same time frame (Chang, et al; 2022).

Among these results, a significant increase of infections was found in schools with a higher percentage of population and those where preventive or sanitation measures have not been stablished properly.

Likewise, authors Vijetha Koppa and Jeremy West mention in their study that per million inhabitants in the United States, in-site teaching generates 54 more new cases and 1.7 more deaths per day, as opposed to hybrid teaching which generates 22 more new cases and 0.5 more deaths per day (Koppa, West; 2022).

On the other hand, there is an article presenting a stochastic Markov Chain model, which estimates the required duration of confinement in Kuwait (Zoughool, et al; 2022).

Authors Zoughool, et al. conducted a stochastic Continuous-Time Markov Chain analysis using an eight-state model that represents the disease transmission and spread of COVID-19 in different places.

Their study finds out that even though a 10 day lockdown before the pandemic peak for 90 days was optimal, the realistic duration would be of 45 days so it can achieve reduction of infections and hospitalization by 45% in Kuwait (Zoughool, et al; 2022).

Simulation has also been used as a mean to evaluate the impact of COVID-19 on prevention measures in Austrian schools by using agent-based simulations and cluster tracing data (Lasser, et al; 2022).

Likewise, simulation has been used to model some security and sanitation protocols for the safe return to classroom instruction in France. For this study, authors used a stochastic discrete age-structured epidemic model based on demographic and age profile data.

Authors established four age classes and used social contact matrices measured in France in 2012 in order to account for the mixing in each age group depending on the type of activity and place where contacts occur (Di Domenico, et al; 2021).

Owing to those last works, a simulation of discrete events was implemented based on various factors specific to the region as well as on the decisions established by the respective governments as security measures.

3. Problem description

The return to face-to-face classes at the Elementary level has become a challenge for Mexican education since students´ health and integrity must be ensured through the various disinfection protocols established by the government.

However, the fact is that a big rate of schools lacks the adequate infrastructure to prevent contagion, and those schools that do have it, endure inefficient or quite long-time disinfection systems, which affect the study and learning time of students (Alvarado, 2021).

In this sense, a private school in the town of Toluca, State of Mexico was selected. It has a staff of 366 students enrolled until August 2021.

This school follows the sanitary filters established by the Mexican government for the return to face-to-face classes, which are composed of different modules such as temperature taking, hand washing, full-body disinfection, and disinfection of backpacks.

During the period from August to November 2021, this school housed half of the students initially enrolled, that is, approximately 180 students.

The entrance was scheduled at 8:00 a.m., considering an hour as part of the process to properly disinfect every one of the attending students without affecting their school day.

However, the school authorities sought to know if their current infrastructure would be enough to receive their initial enrollment of 366 students and carry out the proper disinfection process on each one ensuring no affectation upon their learning activities.

For this reason, a discrete event simulation was carried out to study the average disinfection time for all students since their arrival to school so as to find out how much time is deducted from the effective class time.

The objective was then to determine the necessary corrective actions to minimize the impact of the time investment on student learning process either on to increase the teaching time in-site classes or in any case, to increase the number of sanitization stations.

4. Methodology

To start with the analysis of times which respect to each of the disinfection stations, an information survey was carried out on the construction of the sanitization process, which is shown below.

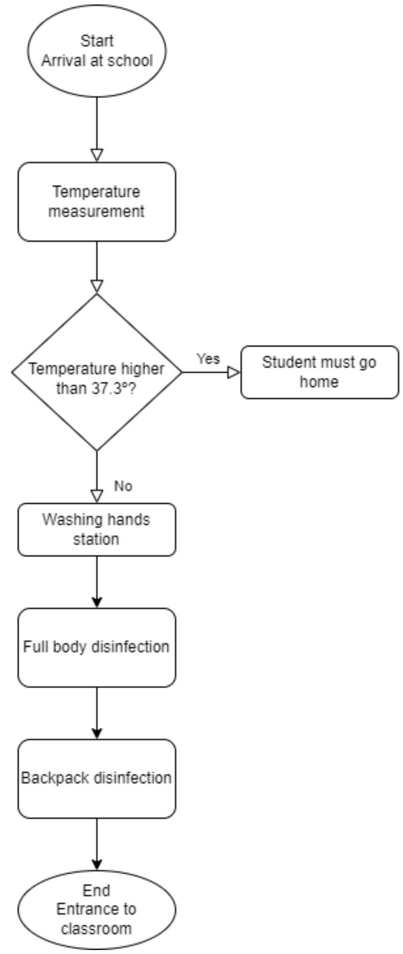

Figure 1. Disinfection stations process diagram

As can be seen in Figure 1, the disinfection process begins with taking the student´s temperature, followed by the handwashing station where students follow the process recommended by the Mexican Ministry of Health.

Once the above is done, the whole body is disinfected with specialized disinfection equipment; finally, the disinfection of backpacks and other school materials that students bring with them, as well as review of the correct use of face masks.

4.1. Resources

There are several human and physical elements the school reckons in order to cope with this process, which are:

- Four disinfection stations.
- Two thermometers.
- Four tables.
- Twelve chairs.
- Two disinfection mats.
- Eight washbasins.
- Face masks.

- Antibacterial gel.
- Disinfectant.
- Soap.
- Eight teachers.
- One nurse.

Two of the eight teachers assigned to this task are located at the temperature station, two at the hands washing, two at the full-body disinfection station, and two more at the backpack and school material disinfection station

The nurse, on her part, acts as supervisor of the whole process, monitors and provides support to the staff, and attends to any possible incident. Materials are stored in a warehouse and are gradually used as they are required.

4.2. Variables and Key Performance Indicators

The input variables declared for the system are:

- Time at each disinfection station.
- Time of arrival of students´ at the school.

In that order of ideas, as the main objective is to define if the time given for the disinfection of students affects the effective school day, we can determine these as the Key Performance Indicators (KPI) to monitor in the system.

Performance indicators directly depend on the number of disinfection stations and the time spent at each disinfection station. They are also related to the rate of students´ arrival to school and the time of study. In the same way, this model can take the KPIs as output variables since they are the same points to measure and monitor.

In summary, the Performance Indicators and output variables of the system are:

- Total sanitization time (from the first child to arrive to the last child to leave).
- Effective study day.

4.3. Data collection and analysis

A Data was collected by taking the students' arrival time to school. This data collections were done by direct observation.

A sample of 425 data points were taken for each of the disinfection stations. These data were collected over one week at the school under study.

In the same way, the time that the student spends in each of the disinfection stations was taken. From this information, the following table was obtained:

Table 1. Times at each disinfection station.

	Temperature	Handwashing	Full body	Backpack
Maximum time	17	140	23	87
Minimum time	3	100	15	4
Average time	8.32	121	19	24
Standard Deviation	3.51	11.88	2.64	12.89

Time is presented in seconds

The above cited table shows the average and standard deviation for each disinfection station. These data are the one that will be used later for the simulation because they are the parameters that will be programmed for each station in the simulation model.

Now, an interdependence analysis of the collected data is required to know the probability distribution they resemble and to know if the collected data is random. This Interdependence analysis was performed with the StatFit software for each of the workstations and consists of the following tests:

- Analysis of descriptive statistics.
- Scatter and autocorrelation plots.
- Runs test.
- Goodness of fit test.

4.3.1. Interdependence analysis for data

As mentioned above, several interdependence analyses were performed for data collected at each disinfection station.

In this section, an example of each of the tests performed is presented, in which it is possible to observe not only the interdependence of the data but also the distribution assigned to each disinfection station.

First, there is the analysis of data dispersion and autocorrelation. In this test, the graphs obtained from the StatFit software were analyzed, in which the dispersion of the data can be observed.

An example of the scatter plot obtained is as follows:

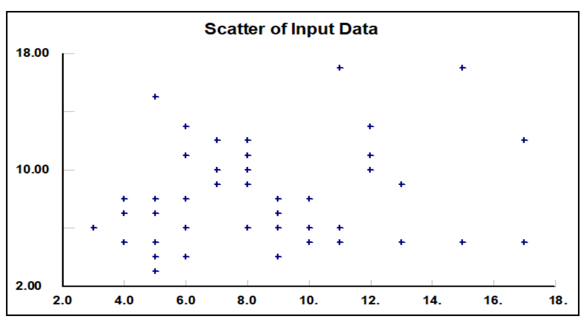

Figure 2. Example of a Scatter plot obtained.

As can be seen in Figure 2, the scatter plot shows times in seconds spent at the temperature taking station. Thus, the vertical and horizontal axes of the graph represent the time spent at the station, with a lower limit of 2 seconds and an upper limit of 18 seconds, since the minimum and maximum times obtained from the descriptive statistics were 3 and 17 seconds, respectively.

Likewise, the above diagram does not show any trend, therefore, it can be assumed that there is no dependence on the data from any station.

On the other hand, the autocorrelation value was obtained for each disinfection station, in which it can be observed that the autocorrelation graph is not close to any extreme.

Instead, it is close to zero and it is social between the positive and negative regions, so it can be assumed that there is no autocorrelation.

The graph that represents the aforementioned is the following:

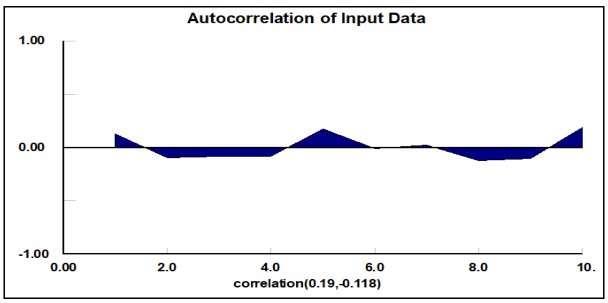

Figure 3. Example of an Autocorrelation plot obtained.

Moreover, the results of the runs tests do not reject the initial hypothesis (data are random), thus we can say the data is aleatory.

Finally, the goodness of fit test was also made with the StatFit software; this program uses tests such as Anderson-Darling, Chi-Squared and Kolmogorov-Smirnov to determine the statistical distribution that best fits the data obtained.

For this case, the results of the goodness of fit test showed that there is insufficient evidence to reject the null hypothesis (there is no significant difference between the observed sample distribution and the expected probability distribution).

This means the data resemble the Poisson distribution, with the respective means in seconds for each station, as shown in the following figure:

autofit of distributions

distribution	rank	acceptance
Poisson(8.32)	100	do not reject

Figure 4. Example of Fit of Distributions.

In this sense, the following table shows a summary of the distributions tested and the one that best fits the data, according to the software StatFit.

Table 2. Distributions tested and selected at each disinfection station with their respective parameters.

	Temperature	Handwashing	Full body	Backpack
Distributions tested	Binomial, Poisson	Binomial, Poisson	Binomial, Poisson	Binomial, Poisson
Distribution selected	Poisson	Poisson	Poisson	Poisson
Average time	8.32	121	19	24
Standard Deviation	3.51	11.88	2.64	12.89

Parameter´s times are presented in seconds

4.4. Assumptions

For this simulation, it was necessary to make some assumptions to justify the way in which we developed the simulation of our process. The assumptions made are the following:

- All days have similar time behavior, so it is not necessary to analyze the data day by day during the week.
- Teachers do not have significant attrition during the process to assume that at some point, they become slower.
- Teachers at the disinfection stations are always the same.
- The total time taken to disinfect all children is time deducted from the school day.

4.5. Simulation Model

The elementary school of this study case has a current model with two temperature stations, eight washbasins, two full-body disinfection stations and two backpack disinfection stations.

This infrastructure is sufficient to make the disinfection process for 180 students (49.1% of the total) without affecting their effective study day.

In this sense, the total disinfection time of the students is 49 minutes, which does not affect their study day because they start arriving at school at 8:00 am. Thus, three different scenarios were proposed to determine the distribution and number of stations that best suited to accommodate the total number of students (366) without affecting their effective study day.

The simulations were carried out under a discrete event simulation model using the FlexSim® software, which has the necessary elements and characteristics to model the process.

The simulation elements used in the three scenarios are listed as follows:

- Source: Used to simulate the arrival of children at school.
- Queues: Used to simulate waiting lines between one sanitizing station and the other.
- Processors: used to simulate the operating times of each disinfection station.

4.5.1. Base model

First, a base model was made with the current situation of the school, i.e., a simulation model was made with the school's current infrastructure to perform the disinfection of the 180 students.

This infrastructure consists of 2 temperature stations, 8 washbasins, 2 full-body disinfection stations and 2 backpack disinfection stations.

This model was validated by the educational institution and the owners of the processes. Based on the validation of this model, three different scenarios were proposed, which are presented in the following section.

4.5.2. *Simulation model scenarios*

In order to monitor the KPIs of this case study, three different scenarios were proposed, for which their respective simulation model was carried out in the FlexSim® program.

Each of the scenarios has some improvements and modifications regarding the number of disinfection stations. These scenarios are presented in the following table:

Table 3. Number of disinfection stations per scenario

	Temperature Stations	Handwashing Stations	Full-body Stations	Backpack Stations
Scenario 1	2	8	2	2
Scenario2	2	10	2	2
Scenario 3	2	10	2	3

For scenario 1, a simulation was developed with the FlexSim® program considering the 366 students with the current infrastructure (the base model Infrastructure) to verify the feasibility of a fully face-to-face return that was programmed for the 2021-2022 school year.

In this way, the model looks as follows:

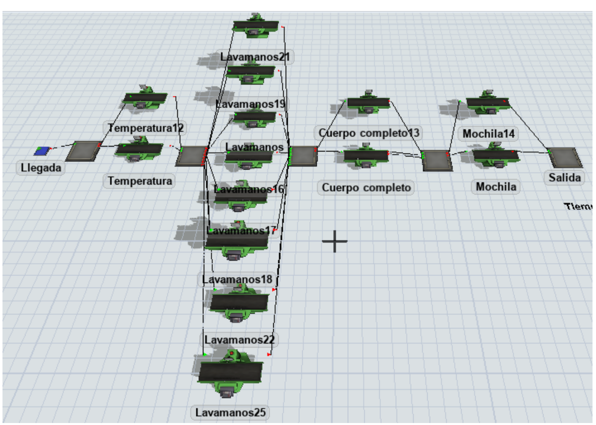

Figure 5. Scenario 1: Actual simulation model for 366 students

On the other hand, scenario 2 consisted in adding 2 more washbasins, having now a total of 10 washbasins. This improvement was done because it was identified that this station is the one that generates a bottleneck since it is the station that takes the longest time.

The addition of the 2 hand-washing stations was done by adapting 2 drinking fountains that the school had available to convert them into a hand-washing station and thus speed up the flow of students.

The resulting model is shown below:

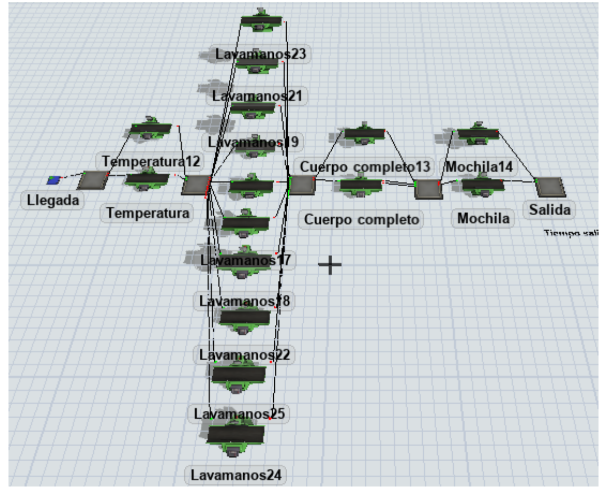

Figure 6. Scenario 2: 10 washbasins

Finally, for scenario 3 it was decided to add one more backpack disinfection station. This decision was made because it wasn´t possible to add another handwashing station due to the school´s lack of infrastructure and when carrying out the time study, we realized that the second station that consumed the most time was the backpack disinfection station.

The simulation model for scenario 3 is the next one:

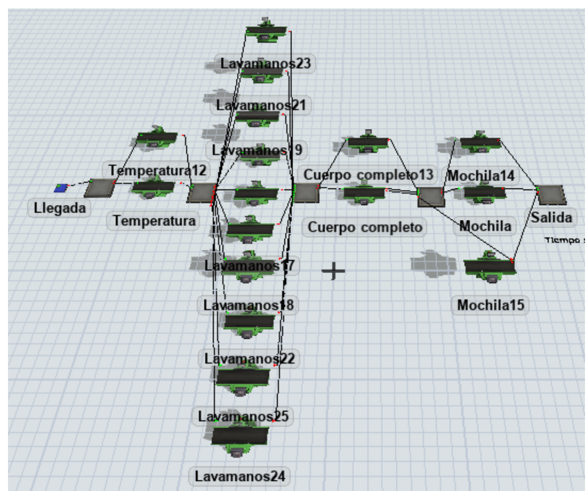

Figure 7. Scenario 3: 10 washbasins, 3 backpack stations

5. Results

Each of the simulation models were subjected to 30 iterations, to verify the impact of the sanitization process time for 30 days (approximately one month).

These replications show the exit time of the last student in the disinfection process for each scenario during the 30 events of the experiment.

A confidence level of 95% was used for each experiment to obtain the maximum, minimum, mean, and standard deviation of the experiments for each model in order to monitor the performance of the modeled systems before and after the improvements were made.

The iterations were performed with the Experimenter add-in of the FlexSim® software. The results of these replications are shown below.

Table 4. Experiment results for each model.

	Scenario 1	Scenario 2	Scenario 3
Maximum time	1.59	1.28	0.999
Minimum time	1.57	1.26	0.992
Average time	1.58	1.27	0.990
Standard Deviation	0.42	0.30	0.12

Time is presented in hours

As can be seen in the table above, the result of the replications shows that for scenario 1 (current model for 366 students), the average time it takes for the last student to exit the system is 1.58 hours.

This indicates that after one month, with the infrastructure currently placed at the school, the disinfection of the students would be completed in 1.58 hours, i.e., it would take almost double the time currently spent (1 hour) for the disinfection of the students.

For scenario 2 (10 washbasins), the average time it takes to disinfect the students is 1.27 hours, which means that disinfection would be finished at 9:16 am. This implies that, with scenario 2, students would be losing 16 minutes of the effective study day.

Finally, for the case of scenario 3 (10 washbasins and 3 backpack stations), the average time in which disinfection of students is completed is 0.99 hours; that is, disinfection would be finished a little before one hour.

In other words, the disinfection of all students in scenario 3 would conclude at 8:59 am. This means that in this scenario it is possible to perform the disinfection of all 366 students in the time that the school has established to perform this process (1 hour) without impacting in any way the effective study day of the students.

A summary of the above is shown below:

Table 5. Results summary.

	System exit time hour [a.m.]	Lost school daytime [min]	% Of class spent
Scenario 1	9:35	35	58.3%
Scenario 2	9:16	16	26.7%
Scenario 3	7:59	0	0%

Time is presented in hours

Based on the above table of results and the previous analysis, we can say that the most feasible scenario to be implemented in the return to face-to-face classes is scenario 3, in which there are 2 temperature stations, 10 washbasins, 2 full-body disinfection stations and 3 backpack disinfection stations, since it is the one that takes the minor time of the school day and is the most feasible one to implement for the school due to their current infrastructure.

6. Conclusions

Specifically in Mexico, in-side teaching was a challenge since two sectors of the population had not received the COVID-19 vaccine by the time they returned to face-to-face classes. These two sectors correspond to children and adolescents between 0 and 15 years old.

Given that there is no literature that addresses this problem in Mexico, it was necessary to conduct a study focused on returning to face-to-face classes ensuring children's health and minimizing the probability of contagion at school.

Unfortunately, because of the type of problem, it is not possible to do such significant pre-testing because this would mean putting the students at risk. For this reason, tools such as simulation are used to model these situations without having to put anyone at risk.

The simulation was very useful since it helped in the process of analyzing the total return of a private elementary school.

It allowed us to locate where the potential risks were in the disinfection process so that they could be corrected in time and so that their return model would work properly when it is carried out in January 2022.

From the analysis, it can be concluded that, with the current model (scenario 1), it would take the school 1 hour and 35 minutes to perform the complete disinfection so 35 min of the effective school day would be lost, which represents a full class.

From the simulation, it was observed that, in scenario 1, the most problematic operation is hand washing since, due to protocol, each student must wash his or her hands for 2 minutes. This operation is the bottleneck in the process.

Additionally, there is a considerable amount of idle time at the other stations as they must wait for everyone to go through the hand washing.

Based on all the analyses previously conducted, the following recommendations are made for the disinfection process of elementary school students:

- Due to handwashing is the bottleneck, it is recommended that two additional washbasins be added to the handwashing station, to avoid wasting time of the actual study daytime.
  The suggested way to have two additional washbasins is to adapt two drinking fountains that are currently available to function as washbasins.
- It is also recommended to add one of the backpack disinfections stations because this process was the second one that consumed a lot of time in the disinfection process.
  By adding one more backpack station, the school can finish the disinfection process of the whole 366 students in the time that they had to do this

activity (1 hour) without reducing the effective study daytime for the students.

To carry out this action, it is essential to place another teacher who oversees carrying out the disinfection of backpacks in this new station.

- Finally, it is recommended that the rest of the areas (full-body disinfection and temperature) remain with the same number of stations since adding more stations would not bring any significant reduction in service time.

7. Future work

The simulation work presented is neither absolute nor definitive since the pandemic situation is changing as time goes by.

For this reason, this simulation should be updated periodically and each time it is done, an analysis should be made so that it can be improved, and better proposals can be found to carry out disinfection as the needs of this process change.

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