A simulation based approach to model SARS-CoV-2 spread in assembly lines

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Abstract: The recent SARS-CoV-2 outbreak has challenged companies, from both service and industry sectors, to reorganize how their business are operated in order to guarantee continuity to their operations while maintaining proper and safe conditions for workers and customers as well. In fact, a recognized preventive measure against the coronavirus spread, that has been adopted by many governments all over world, is to limit as much as possible and to make safer social interactions in the workplace. The effect of such measures is very impactful on those activities that require physical presence or a direct interaction with physical resources such as shop floors. For example, on an assembly line, it could be more difficult for operators to maintain appropriate distances if the new workplace and the new working conditions have been attentively conceived and deployed. This paper has the objective of showing how computer simulation can support companies in this complex task and, at the same time, of providing an operational tool and a case study application. Particularly, it uses a computer simulation tool (i.e., AnyLogic), to model and evaluate alternative design solutions with the aim of making the considered shop floor more resilient from the coronavirus spread perspective. We focused on the automotive sector and considered the case of a two-sided single model assembly line and the related surrounding areas. Various reconfigurations of the assembly line were considered with the aim of reducing contagion likelihood during production. In order to increase the distance between operators, we compared different solutions involving centralized and decentralized warehouses as well as collaborative robots (i.e., cobots). Each configuration was also tested with respect to the individual protection parameter, i.e., we explicitly considered the type of protection the operators use while performing their activities (no mask, surgical or FFP2 mask).

Keywords: Covid-19; Pandemic; Assembly line; Manufacturing; Industry 4.0;

1.Introduction

The word "pandemic" is derived from the Greek word "pandemos" meaning "that which affects the entire population." The pandemic represents the spread of an epidemic disease in large geographical areas on a global scale. The disease and the risk of contracting it consequently involves a large part of the world's population.

Throughout history, humanity has been faced with the emergence of global epidemics that have wiped out millions of people and caused political and economic crises. The pandemics that have most affected the world have been the Italian Plague, Cholera, Yellow Fever, Spanish Flu, Polio, AIDS, SARS and Ebola. Today, with the increase in international travel, urbanization and globalization have allowed infections to spread throughout the world (Graversen et al., 2020).

In recent years, bacteriological epidemics, including the SARS CoV-1 outbreak in 2003, Ebola in 2014 and MERS in 2015, the Anthrax threat in 2001, have become more frequent (Esterwood & Saeed, 2020). This increase in the spread of viruses may be due to increased world travel resulting in increased transmission of infections between people.

COVID-19, unlike other pandemics, has a high mortality rate and is continuously increasing precisely because coronaviruses are well known for their ability to mutate. In fact, genetic recombination with subsequent transmission from animal to human can lead to new genotypes and outbreaks. At the end of 2019, the World Health Organization (WHO) was alerted by Chinese authorities of pneumonia-like cases in the city of Wuhan.

In this pandemic era, the economic and social consequences will last far longer than the health emergency. Therefore, it is necessary to identify a new development trajectory for the country that takes into account the production sectors most affected by the crisis triggered by COVID-19 and that, at the same time, allows to increase the objective and subjective well-being of people both from a health point of view and from a social and employment point of view.

With the outbreak of SARS-CoV-2, many small and medium-sized companies faced numerous difficulties related to productivity and worker's safety. Therefore, many companies preferred to close their businesses because they were found to be unprepared to shoulder that load.

In order to meet the needs of manufacturing companies, this work aims to analyze the spread of the virus in a workplace setting. Through the support of computer simulation, we investigated innovative solutions for workers' safety. In particular, several scenarios of an assembly line in the case of an automotive company have been analyzed. By means of the computer simulation package AnyLogic, we have compared various solutions, that exploit also the potential of I4.0 technologies, to control and minimize the spread of viruses.

After an analysis of the literature of recent years, seen in section 2, we turn to the structure of the methodology that led us to define the scenarios, in section 3. In section 4 we analyze the results and discuss the solutions adopted. Finally, in section 5 we give the conclusions and future research of this work.

2.Literature review

The spread of infections due to COVID-19 virus has been shown to occur predominantly by airborne route (Zhang et al., 2020; Morawska & Cao, 2020). Notably, several studies have shown that in addition to droplets, generated by infected persons, COVID-19 can also be transmitted via submicron aerosols (Prather et al., 2020). Because of their small size, aerosols can penetrate deeper into the lungs, resulting in high COVID-19 disease severity (Buonanno et al., 2020). Bontempi (2021) after having analysed data on infectious cases detected in five EU member states concludes that wearing a face mask, practicing social distancing and proper hand hygiene, cancelling public events, and limiting carrying capacity should be recommended to reduce the chances of contracting the virus.

Therefore, several solutions can be adopted to combat the disease, including the use of face masks and social distancing. When an individual wears a face mask, transmission of respiratory viruses can be prevented by reducing respiratory droplets and aerosol routes (Leung et al., 2020).

The effectiveness of a facemask or respirator is determined by two significant factors: filtration efficiency and fit (Oberg & Brosseau, 2008). Filtration efficiency measures how well the mask filters particles in a specific size range, which includes viruses and other small particles, while fit measures how well the mask or respirator adheres to the face to prevent virus leakage.

Face masks are divided into two different categories: surgical masks and FFP respirators. Both categories are Personal Protective Equipment (PPE) and are used for respiratory protection. Surgical masks have a maximum use time of 4 hours and have a 20% protection rate. FFP respirators are divided into three classes (1 to 3), have a maximum use time of 8 hours, and have percentages of protection ranging from 80% to 99% (Lepelletier et al., 2020). The use of masks is strongly recommended by the World Health Organization and specifies the indications on how to wear them in the update of February 2020 (WHO, 2020).

The COVID-19 pandemic has caused a massive economic collapse across the globe, with customer demand and industry activity plummeting terribly. This can be seen in the data collected from business activity across the Eurozone, which plummeted to historic lows in March 2020.

The International Labor Organization predicts that manufacturing will be one of the hardest hit sectors in terms of the negative impact on economic output (ILO, 2020).

There are few research articles studying safety strategies to cope with the spread of COVID-19 in manufacturing companies. While many studies deal with the creation and use of PPE see for instance Hasan et al. (2021); Huang et al. (2021); Jeanmonod et al. (2021); Sterman et al. (2021).

It is therefore essential to intervene in workers' safety, not only with the support of PPE, but also with the support of rules that make their lives, also in working environments, more secure (Gaitens et al., 2021).

Thanks to the rapid evolution and widespread availability of information and communication technologies also in industry, many manufacturing companies have been implementing the so called Industry 4.0 technologies. Today, these tools can help us not only to make production more efficient but also safer. Javaid et al. (2020) describe ten Industry 4.0 technologies that could provide many innovative ideas and solutions to respond to local and global medical emergencies. Among these technologies are collaborative robots (cobot).

In various areas, the use of robots during the pandemic has helped businesses overcome many obstacles. Diagnosis, screening, disinfection, surgery, telehealth, social, care, logistics, manufacturing are among the fields in which Shen et al. (2021) have explored the benefits of using robots.

Li et al. (2020) created a new Intelligent Manufacturing framework for production recovery during pandemic and evaluation of industrial facilities using I4.0 tools such as Big Data and Industrial Internet of Things. They also assessed the reduction of health risks to workers by optimising layout to maximise social distancing between operators.

As a consequence of this literature review, it is apparent that very few studies support the decision making process to efficiently reorganise the production system while preserving worker's safety.

3.Methodology

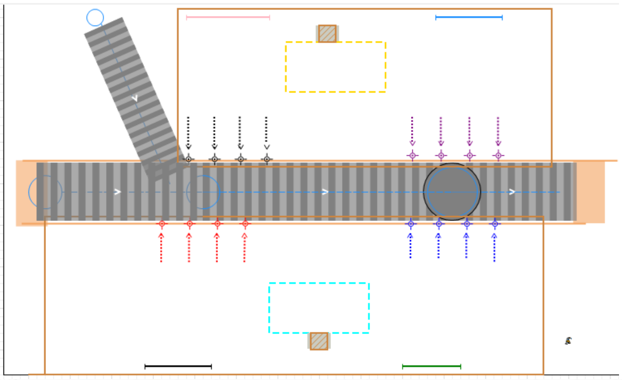
In this section is presented the methodology that led to the creation of the simulation model useful to reduce the possible inconveniences given by an event like COVID-19 for the safety of the workers.

In this regard with the support of the computer simulation tool AnyLogic, the case of an automotive assembly line was analysed under a pandemic crisis.

Several configurations of a two-sided assembly line with two workstations and 16 workers were analysed. Starting from the current layout, we first modelled and simulated two configurations corresponding to the types of warehouse, that could be used to serve the line:

1) the case of a centralized warehouse for each side of the line (i.e., supermarket);

2) the case of decentralized warehouses each dedicated to a certain station in the stations of job (see Figures 1a and 1b).



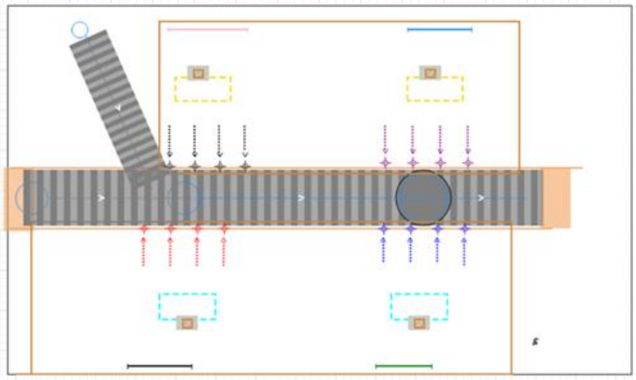


Figure 1- Resulting configuration of assembly line with centralized warehouses (a) and decentralized warehouses (b)

The simulation models allowed us to visualize how the infection due to COVID-19 spreads across the assembly line. For the two above-mentioned configurations, five different worker operating conditions were investigated:

1. workers without mask
2. workers with chirurgical mask
3. workers with FFP2 mask
4. workers with chirurgical mask and cobot
5. workers with FFP2 mask and cobot

Turning to some details concerning the simulation models, it is worth noting that the duration of each simulation is 480 minutes, which corresponds to an 8-hour work shift.

The worker is represented with a circle that can be red or blue depending of in health state. This circle has a radius corresponding to 1.5 meters and this radius makes apparent the distance between the workers. When this distance is not maintained a certain “passage of state” (i.e. change of color) of the workers occurs. The circle has a blue color when the worker is in a healthy state, while it is red when he is in an infected state. It is worth highlighting that the color transition occurs gradually from blue to red, when an health worker approaches an infected one. In each simulation run the average number of infected workers is 6.

As for the spread of the virus, it is modelled by the variable "Infection". Each infected worker sends a message to five neighbour workers, i.e. to those entering his circle. This message has the object "Infection" and the infected agent sends 1 message per second.

Finally, in order to take into account the protection degree of the various the types of mask, the simulation model uses the variable "Protection" that is pictorially represented by a slider. This variable can take values the interval [0,1], where 0 represent the case without mask, 0.2 represent the case with chirurgical mask and 0.92 represent the case with FFP2 mask. The variable "Protection" is a threshold value that allows to determine the probability of contagion.

The simulated scenario considers that workers, during operations, move from the assigned assembly station to the warehouses present on the shop floor. When workers are at assembly station, because of the workplace organization, they can maintain social distances and are less exposed to the risk of being infected. On the other hand, the risk of infection significantly increases when workers enter the warehouses.

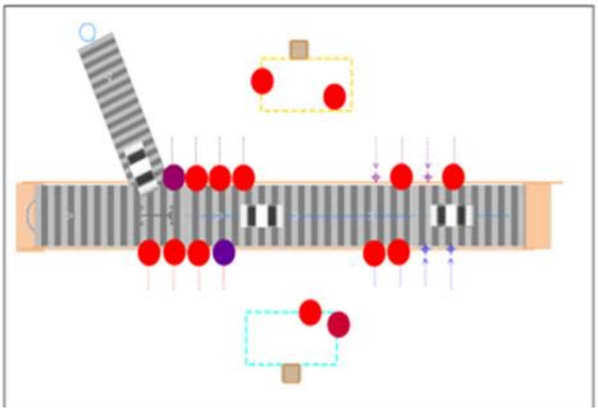


Figure 2- Screenshot of the simulation model with centralized warehouses

Some experimental settings consider the fact that some workers are replaced with collaborative robots. In these settings to improve workers’ safety, we hypothesized to reorganize the assembly line by using cobots and fewer workers so as to expand the social spacing between workers at the assembly stations and limit their movements in the work area. It is worth pinpointing that using cobots does not necessarily imply reducing the workforce level but reorganizing their work. The workers will be able to participate to refresher or training courses and then be assigned to cobots configuration and supervision or office activities while being of support to production activities in case of problems with supplying materials to the line or replacing sick workers.

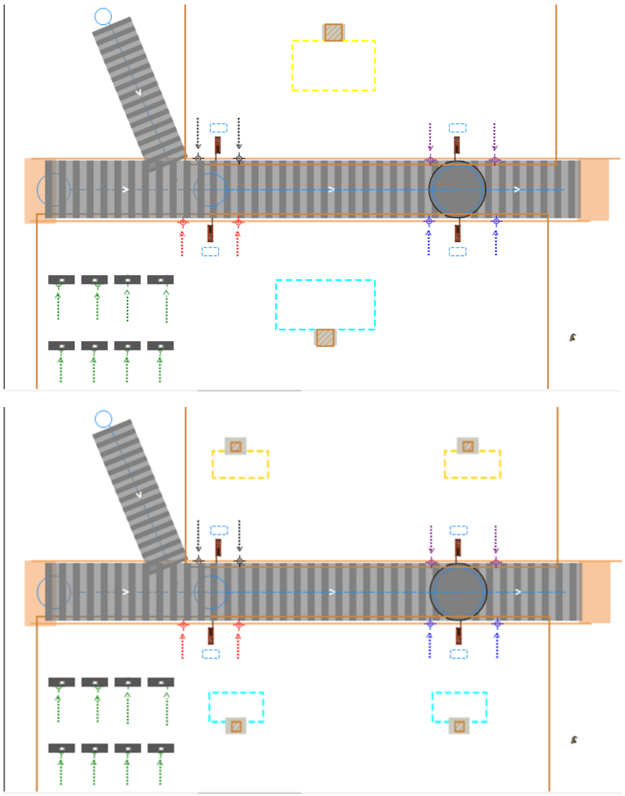


Figure 3- Resulting configuration of assembly line with cobots and centralized warehouses (a) and decentralized warehouses (b)

4.Results and evaluation

This section presents the results of the simulations performed. A first benefit of these simulations could also be an increase in productivity as assembly times are lower if compared to the times of a mainly manual assembly line. This reduction will lead to an increase in throughput of this section of line, in fact, the simulation results show that its average value goes from 175 to 180 products per shift.

This reorganization requires, an office area for all the workers replaced by the cobots, while on the assembly line there will be only 8 workers alternated by the presence of the cobots. In this case, the cobots have their own small area for picking up material, while the workers retrieve materials for assembly from the warehouse assigned to the station.

In order to obtain more accurate estimates, we exploit the Monte Carlo method, which uses randomness to obtain meaningful information and is effective for calculating the variability of interactions occurring on the line.

For a stochastic model it may be necessary to simulate multiple runs to get a more reproducible evaluation of system behavior.

For this reason, it was experimentally estimated that with an average of 50 repetitions more reliable results are obtained (Fig. 4).

Figure 4- Monte Carlo simulation results; a) Protection=0; b) Protection=0.92

In detail, Figure 4a shows the results of 50 simulations obtained with the Monte Carlo method in the case of the assembly line with workers without masks (Protection = 0) and two centralized warehouses. In Figure 4b instead are reported the results of the case where workers are wearing masks type FFP2 (Protection = 0.92), with cobot and with the use of four decentralized warehouses.

Finally, a comparison among different simulations, keeping constant the number of infected workers at the beginning of the work shift is carried out. As can be seen from Table 1, considering a number of 6 infected workers, the results show that the number of infected workers at the end of the work shift goes from 15, in the case without a mask and two centralized warehouses, to 6 (i.e. no new infected workers) in the case of a FFP2 mask, cobots and four decentralized warehouses.
It should be noted that two experiments of the 12 full factorial designs are missing from Table 1, as they are irrelevant to the objective of the study.

Table 1: Results of Monte Carlo method

Simulation of the sub-cases for each type of warehouse	Individual protection	Number of infected workers	
		Two centralized warehouses	Four decentralized warehouses
Workers without mask	0	15	13
Workers with chirurgical mask	20%	14	11
Workers with FFP2 mask	92%	10	8

Workers with chirurgical mask and cobot	20%	8	7
Workers with FFP2 mask and cobot	92%	6	6

5.Conclusion and future research

With the SARS-CoV-2 outbreak, many small and medium-sized businesses faced numerous challenges related to productivity and worker safety. Therefore, many managers preferred to close their businesses because they were found to be unprepared to shoulder that burden.

Given all the difficulties that have been and may still be faced, it was decided to use the Anylogic tool to evaluate possible solutions for an assembly line in an automotive industry.

Results of the simulations highlighted that the evolution of contagion decreases with the use of surgical masks or FFP2 and with the reorganization of the assembly line with the introduction of cobots and the resizing of the warehouses.

There are companies that cannot face cobots cost since is a great investment the first alternative solutions of a safer workers' re-layout organization is the warehouses decentralization allowing to limit workers contact and to reduce pick up materials time implying assembly line increased productivity.

With the introduction of cobots in the assembly line there will be a reorganization also of the working activities, since some workers will be able to carry out different tasks, they will be positioned in the offices as line support, they will help to make orders of some equipments or to replace on the line sick workers. Also, in the offices, it is important to ensure social distancing between operators with plexiglass panels and pedestrian signs.

To further improve the assembly line, industrial robots may be replaced by collaborative robots to optimize space, ensure greater worker safety, and improve productivity.

By adopting such changes, companies may better react to COVID-19 and future pandemic crisis.

For future research we could consider implementing the model by halving the number of workers on the shift, but running the risk of new positive entries to the virus. A cost analysis for companies that decide to use a multi-store solution or the use of cobots as a safeguard strategy can be implemented in the future. Finally, one could evaluate the company's strengths of relocating people, who support the line with cobots, to a new assembly line.

In addition to the mentioned, there are other aspects that could be analysed in a future work. Aspects of virus spread in other areas such as in the canteen, changing rooms, corridors and common areas could be analysed. Data modelling approaches could be extended to identify different solutions using Markov chains.

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