Resilience of Assembly Lines in Automotive Industry

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Abstract

A company's ability to manage supply chain resilience is a valuable consideration, especially during pandemics such as COVID-19. For this reason, researchers are increasingly interested in supply chain resilience, particularly in the manufacturing industry, during emerging situations. This study provides insight into the impact of the COVID-19 outbreak on the automotive industry. This paper examines three years of data from an assembly line that produces 500 cars per day, analyzes the impact of the spread of the virus on the efficiency of the assembly line, and suggests improvements to strengthen the assembly line resilience.

Keywords
Assembly Lines, Resilience, Effectiveness, and Pandemics.

1. Introduction
The ongoing Coronavirus disease (COVID-19), caused by the SARS-CoV-2 virus, was first identified in December 2019 in the Chinese city of Wuhan, and was declared a global pandemic by the World Health Organization (WHO) on March 11, 2020 (Lai et al. 2020). Since then, COVID-19 has rapidly spread beyond China to almost every country on the globe (*WHO* 2020), and at the time of writing this article (April 2022) there have been more than 510 million confirmed cases worldwide and more than 6 million of deaths. Otherwise COVID-19 is not only a global pandemic or disease that impacts the health of the human being, it has affected also the global economy and financial markets (Purwanto et al. 2020). Governments worldwide have increasingly undertaken an inhibition strategy to contend the outbreak, relying on widening social distancing, wearing masks, especially in public places and transport, along with various other measures in order to reverse the pandemic growth, and thereby manage the resilience of the healthcare systems. Notably, these measures in turn have often resulted in stricter border restrictions and complete nationwide lockdowns, and in the process thereby, causing a negative short-term impact on consumer spending, investments, and disruptions to international trade and global supply chains (Kumar & Managi 2020). Most governments in the world underestimated the risks of rapid COVID-19 spread and were mostly reactive in their crisis response (Pak et al. 2020). As disease outbreaks are not likely to disappear in the near future, deep analyzing and proactive actions are required to not only save lives but also protect economic prosperity (Pak et al. 2020).

This led us to conduct this study in order to analyze the impact of the pandemic on assembly lines. Therefore, the proposed comparison metric is the Overall Equipment Effectiveness (OEE) launched in 1988 by (Nakajima 1988);

which is used for measuring productivity of equipment and assembly lines. It identifies and measures losses of important aspects of manufacturing namely availability, performance, and quality rate (Williamson, 2006).

2. Literature Review

2.1 COVID-19

At the end of December 2019, an outbreak of unknown pneumonia was reported in Wuhan, Hubei province, China. From the respiratory secretions of affected patients was isolated, a novel coronavirus whose genome analysis indicated belonging to the genus β-coronavirus, lineage B, subgenus Sarbecovirus (Zhu et al. 2020).

On 30 January 2020, The World Health Organization announced a Public Health Emergency of International Concern and on 11 March 2020, COVID-19 was declared as a Pandemic that has now rapidly spread worldwide (*WHO*, 2020). The COVID-19 pandemic has caused direct impacts on the global economy due to premature deaths, workplace absenteeism, and reduction in productivity and has created a negative supply shock, with manufacturing productive activity slowing down due to global supply chain disruptions and closures of factories (Pak et al. 2020).

2.2 Manufacturing Resilience

A firm's ability to manage risk and resilience in supply chains has turned out to be an invaluable capability during the COVID-19 pandemic (Kähkönen et al. 2021). Resilience is one of the key characteristics that manufacturing systems should have as it offers the ability to withstand difficult situations and be able to accommodate disruptions without the incurrence of significant additional costs. (Alexopoulos et al. 2022). Unexpected disruptive events in manufacturing systems always interrupt normal production conditions and cause production loss. A resilient system should be designed with the capability to suffer minimum production loss during disruptions, and settle itself to the steady state quickly after each disruption.(Gu et al. 2015). One key element in building resilience is the development of firms' capabilities. To reduce the impact and to be able to bounce back after the disruption requires a response and recovery ability (Chowdhury & Quaddus 2016). If companies fail in developing readiness, response and recovery abilities, their supply chain will be even more vulnerable (Chowdhury & Quaddus 2016). Mitigating vulnerabilities requires resilience capabilities to remain in the long run, requiring firms to develop dynamic capabilities (Chowdhury & Quaddus 2017).

2.3 Assembly Lines

Until today, the industrial world has been knowing four industrial revolutions; which impacted positively the global economy. Consequently, different industrial tools have been knowing many changes through the aforementioned industrial revolutions (Abbadi et al. 2020). Since the first industrial revolution, manufactured goods were handmade by individual workers in independent workshops, each worker works on his own part using manual tools, and the final product was assembled at the end (Robert 2014). At the end of the 19th century, Henry Ford installed the first assembly line exactly in 1913, which was defined as a group of workstations aligned in a serial manner. The work pieces visit stations successively either manually or by a transportation system, e.g. a conveyor belt (Boysen et al. 2007; Ahmadi & Abbadi 2020; Nelson & Winter 2004) defined the assembly line as an organizational unit, which one can view as a collection of self-sustaining routines. And according to Eisenstein, an assembly line has n workers moving among m stations, where each worker independently follows a simple rule that determines what to do next (Bartholdi & Eisenstein 1996). While Anthony defines an assembly line as a specific assignment of the work elements to a sequence of stations with each element assigned to precisely one station, such that if one work element must precede another, then either it is assigned to an earlier station in the sequence or both work elements are assigned to the same station (Mastor 1970).

2.4 OEE

(Nakajima, 1988) was the first researcher to introduce the OEE as a metric or measure for the evaluation of equipment effectiveness while (Williamson, 2006) defines it as the degree to which the equipment is doing what it is supposed to do based on availability, performance, and quality rate. (Dunn, 2015) defined those three aspects as follows :
(1) availability 'Is the machine running or not?'
(2) performance 'How fast is the machine running?'
(3) quality 'How many products satisfied the requirements?'

Availability (A):

The availability factor measures the total time that the system is not operating because of breakdowns, set-up, adjustment, and other stoppages (Jonsson & Lesshammar, 1999), it is calculated using the (Nakajima, 1988) formula presented below :

$A = \frac{LT-DT}{LT}$ (1)

- LT: Loading time
- DT: Down time

Performance (P):
An equipment should perform at speed of theoretical production output. However, this is impossible in real situation as many hindrances may hinder the equipment from performing ideally (Ngadiman et al., 2013). The performance factor can be calculated using the following formula:

$$P = \frac{IC \times OP}{OT} \quad (2)$$

- IC: Ideal cycle time, it refers to the theoretical cycle time of the line
- OP: Output
- OT: Operating time, it is the time that the equipment is working (producing units):
-

$$OT = LT - DT \ (3)$$

Quality (Q):
The quality factor represents the percentage of defective units to the total units produced in the line, it involves only defective units that occur in that designated stage of production, it is calculated using the following formula:

$Q = \frac{TP-DU}{TP}$ (4)

- TP: Total production, it refers to the total number of products
- DT: Defective units, it refers to the number of defective units

In essence, OEE is the result achieved by multiplying these three factors together:

$$OEE = A \times P \times Q \quad (5)$$

3. Methods

To study the impact of the COVID-19 pandemic on a studied assembly line, data were collected from a 3-year data extraction from a CPMS (Computerized Production Management System) called JDE Oracle over three different periods: Period 1:

- April 2019 – April 2020 (Before COVID period)
- Period 2: April 2020 – April 2021 (During COVID period)
- Period 3: April 2021 – 2022 (After COVID period)

The data used are loading time, downtime, defective units, setup time, downtime, small downtime. Then the OEE factors (Availability, Performance, Quality) are calculated using the formulas (1-5) to calculate finally the OEE level for each period.

4. Data Collection

The automotive industry is a highly competitive sector. Manufacturers must effectively control highly complex production processes in order to fulfil all customer orders for customized cars on time, on budget and to the required quality (El Ahmadi & El Abbadi 2022). Our study took place in a French automotive company, the vehicle in the production process passes through the stamping department, the body department, the painting department and finally the assembly department where our study took place, an automotive assembly line usually starts with the bare chassis (the basic component of a car), then the other components are assembled successively (engine, battery, drive axle, steering wheel, windows...)(AHMADI et al. 2019). The line studied is a manual assembly line, composed of 6 workstations and 10 workers (one worker on the right and one on the left at each workstation) who assemble all the interior parts of the car (accelerator pedal, brake, glove box, seatbelt, handbrake, steering wheel, radio station...) and 2 quality control operators (right and left) as shown in figure 1:

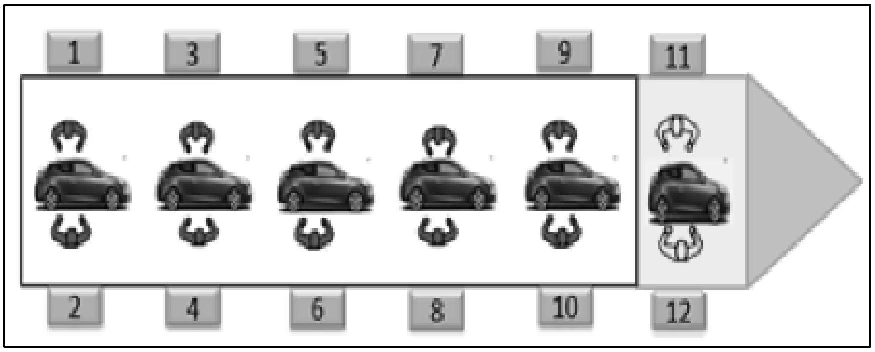

Figure 1. Studied Assembly Line ME5

5. Results and Discussion

5.1 Graphical Results

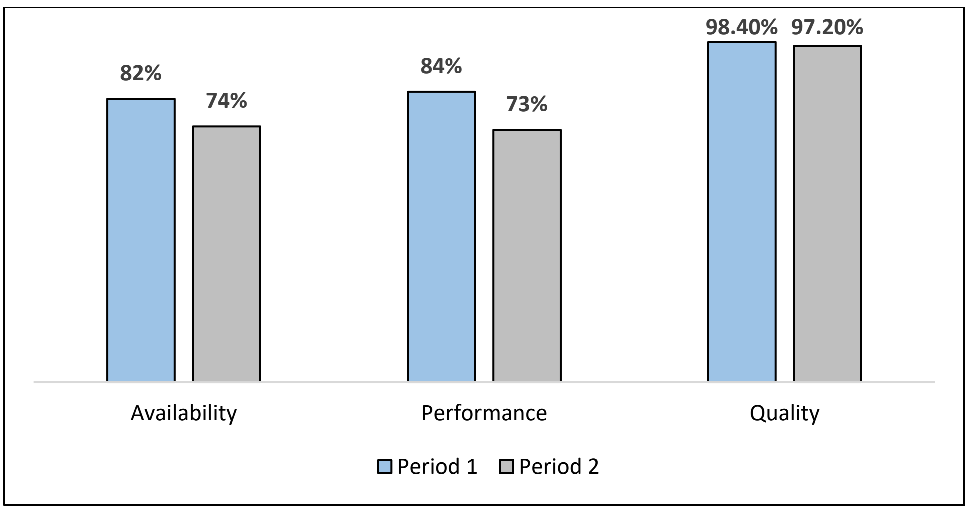

Figure 2. Comparison of OEE factors between before and during COVID periods

As shown in Figure 2, the COVID pandemic had a negative influence on the availability factor, which dropped from 82% to 74%. The performance factor was also affected and dropped by over 13%, while the quality rate was slightly affected.

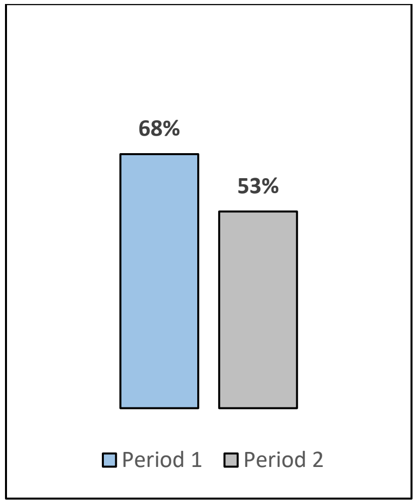

Figure 3. Comparison of OEE between before and during COVID periods

The decrease in the three OEE factors resulted in a significant decrease in the efficiency of the line as shown in Figure 3, the OEE decreased from 68% to 53%.

5.2 Numerical Results

The ME5 line efficiency analysis reveals a significant decrease in term of efficiency (-22%) after the COVID-19 virus spread from 68% to 53%, due to a decrease in all OEE factors as shown in Figure 2. As mentioned above, performance and availability factors have a significant influence and impact on the level of OEE, and this was expected because during the pandemic, many shutdowns occurred due to lack of workers, shortage of raw materials, restricted movements and many other reasons. Therefore, the OEE of the line will be significantly improved by improving these two factors.

5.3 Proposed Improvements

In order to strengthen the assembly line resilience, two main solutions were proposed:
- Industrial Internet of Things and Digitized Supply Chain: using connected assembly lines instead of unconnected manual lines to increase social distancing and making interconnections between machines fully digitized and automated.
- Worker upgrading and requalification: this involves imparting new and different skills to workers so that they can adapt quickly to pandemics and changes in general.
- Respect of sanitary rules inside the factory.

5.4 Validation

The proposed solutions were implemented during the plant's annual shutdown in April 2021: on the one hand, the transformation of the ME5 assembly line into a connected line using RFID sensors, fully digital workstations and self-guided vehicles as shown in figure 4, and on the other hand, the training of workers in order to improve their skills (upscaling and retraining):

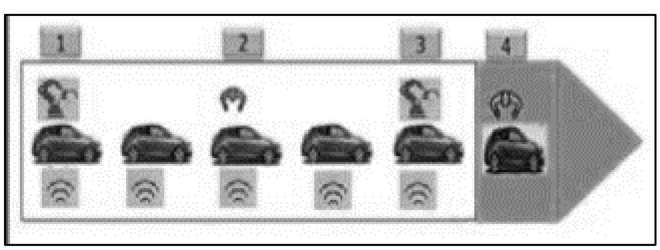

Figure 4. ME5 upgraded line before COVID

In the new configuration, only 3 connected workstations are needed to perform all the assembly tasks of the line instead of 10 unconnected manual workstations as shown previously in Figure 5 and only one quality control operator instead of two, data is again collected to calculate the new OEE factors of the line :

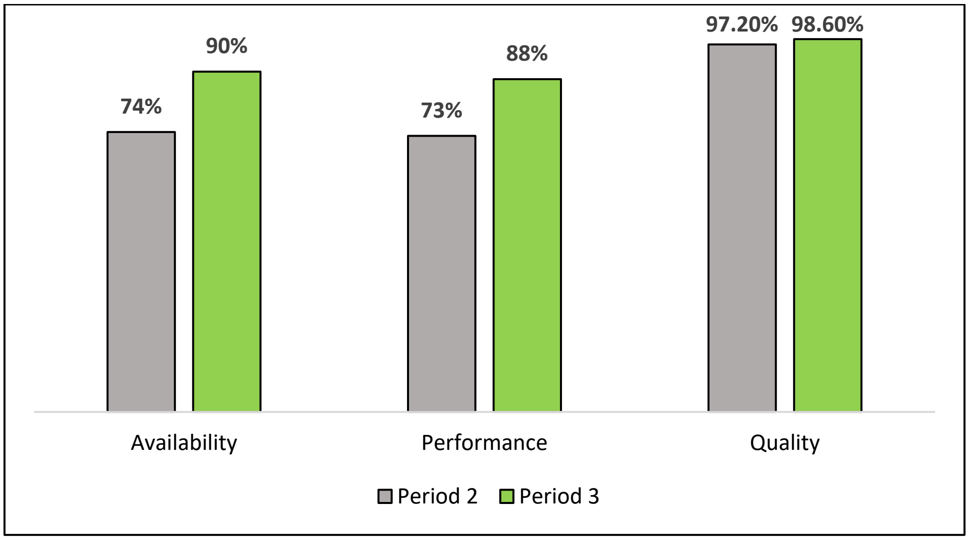

Figure 5. Comparison of OEE factors between during COVID period and after improvements period

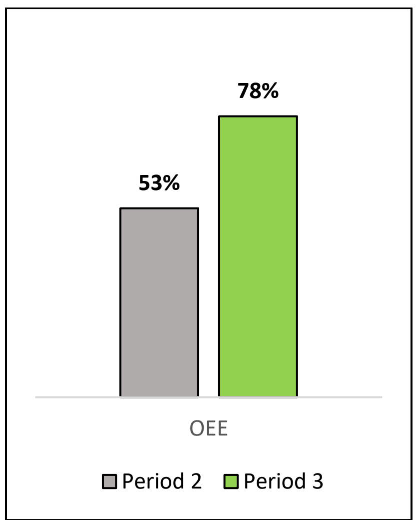

Figure 6. Comparison of OEE between during COVID period and after improvements period

As shown in Figures 5 and 6, OEE improved to excellent levels (78%) that are better than levels during COVID (53%) and even better than levels before COVID (68%), demonstrating the effectiveness of the proposed solutions.

6. Conclusion

The objective of this paper was to analyze the impact of pandemics on assembly lines in order to propose solutions to strengthen the resilience of assembly lines. We mainly focused on the COVID-19 case by studying the case of a manual assembly line in a French automotive company located in the city of Tangier, Morocco. In conclusion of this article, the authors found that manual assembly lines did not withstand waves of COVID-19 spread, and would not withstand future natural outbreaks or pandemics. Therefore, any infectious virus that requires social distancing can have a negative impact on its effectiveness. The overall equipment efficiency of the studied assembly line decreased from 68% before the pandemic to 53% during the pandemic and the most impact is of the availability and performance factors, so improvement solutions for these factors were proposed and studied. The proposed solutions, namely connected assembly lines, workers upgrading and reskilling and respect of sanitary rules, improve the resilience of the studied assembly line to the COVID-19 pandemic in particular (line efficiency increased by 47%) and enhance the resilience of the supply chain in general.

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Biography

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