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A Conceptual Framework for Industrial Digital Transformation in the COVID-19 Pandemic Era

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Abstract

Manufacturing has been hugely affected by the COVID-19 pandemic, with many critical global value chains either halted or seriously interrupted. Most interactions with customers and employees have to take place in a contactless or virtual way. As such, digital operation is the way to remain in business through mandatory shutdowns and restricted activity. To that end, this paper presents a literature review on the acceleration of the digital transformation triggered by COVID-19 as a catalyst in the utilization of Industry 4.0 technologies. Furthermore, a conceptual framework for digital transformation and Small Medium Enterprises (SMEs) business models change is proposed.

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Peer-review under responsibility of the scientific committee of the 15th CIRP Conference on Intelligent Computation in Manufacturing Engineering, 14-16 July, Gulf of Naples, Italy

Keywords: Digital Transformation, Industry 4.0, COVID-19

1. Introduction

Technological unemployment is observed in every industrial revolution, but it is merely a disposition of human workforce, since it is reported that there will be a positive change in the overall job count globally [1]. The SARS-CoV-2 pandemic has had a far greater negative impact on global economic growth than anything experienced in nearly a century. According to estimates, the virus slowed global economic growth to a -4.5 percent to -6.0 percent annualized rate in 2020, with a partial recovery of 2.5 percent to 5.2 percent expected in 2021. In 2020, global trade is expected to fall by 5.3 percent, but it is expected to grow by 8.0 percent in 2021 [2]. The Bureau of Economic Analysis (BEA) reported that US GDP fell 9.0 percent in the second quarter of 2020 compared to the previous quarter, or at an annualized rate of -31 percent, the largest quarterly decline in US GDP in the past 70 years [3].

The International Labor Organization (ILO) estimated that 93 percent of the workers worldwide were living under some form of workplace restrictions as a result of the global pandemic [4], and that 8.8 percent of global working hours were lost in 2020 compared to the fourth quarter of 2019, an amount equivalent to 255 million full-time workers.

The COVID-19 pandemic has changed the global perspective regarding the technological unemployment. By extension, the global priority became to ensure that the virus will not spread, and people remain safe and healthy. Other analysts predicted that the pandemic would have three major effects on the workplace [5]:

- Establishing telework as a permanent presence, with 20% to 25% of workers in developed economies and 20% in developing economies working from home three to five times per week, potentially reducing demand for public transportation, restaurants, and retail stores.
- Expanding e-commerce, which may disrupt travel and leisure jobs, low-wage jobs in brick-and-mortar stores and restaurants and increase jobs in distribution centers.
- Accelerating the adoption of artificial intelligence (AI) and robotics.

The above-mentioned challenges, created a situation in which people who were working, suddenly had to stay home and if remote working was not applicable, then they should rely on their government to provide them an income. It is
very interesting to observe the business model changes that this pandemic created and how it worked as a catalyst for digital transformation. The Industry 4.0 technologies have a vital role in this whole process, since remote working relies on computing power and data management, healthcare system in many occasions rely on robots to treat patients and people shop online the products they need, while the supply chain has to manage the overload of business to consumer sales [6]. It becomes evident from the changes that societies are facing right now, a new model can be envisioned from the counter measures taken against COVID-19. Remote working could be the solution to work-life balance, but social control and movement facilitation constitute a challenge for privacy [7]. Therefore, the aim of this review paper is to examine how the COVID-19 impacted the business landscape and propose a Conceptual Crisis Response Framework, as an outcome of best practices observed in the literature.

The rest of the paper is structured as follows. In Section 2 the research methodology is presented, and the relevant literature is investigated. In Section 3, the review focuses on the COVID-19 as a catalyst for business models and in Section 4 the proposed conceptual framework for digital manufacturing transformation is discussed. Finally, Section 5 presents interesting statistics about the impact of the pandemic and in Section 6 the paper concludes as well as future development directions are discussed.

2. Literature Review

2.1 Research Methodology

For the purposes of this research work, there was a focus on electronic academic papers and scientific articles, as well as many corporate reports indexed in globally accepted databases, namely Google Scholar, Scopus, and specific consulting and tech companies by name in the web. The recently published papers were included in the process, from November of 2019 since the October of 2020. The flowchart of the research methodology that was based on [8] is presented in Fig. 1.

The purpose of this research work is to shed light on the following questions through the investigation and analysis of the literature review.

- How did the COVID-19 Pandemic impact various technologies utilization?
- Which are the key areas that can be evolved because of this healthcare crisis?
- How effective was the global response to COVID-19 and is there a crisis response framework for similar situations in the future?

2.2 Resilient Manufacturing

The Digital Transformation that AI enabled for manufacturing plants and supply networks poses a great opportunity for increasing the resilience and efficiency of manufacturing firms. Additionally, an intertwined supply network (ISN) is a collection of interconnected supply chains (SC) that ensure the supply of goods and services to society and markets. The ISNs provide services to society (e.g. food service, mobility service, or communication service) that are required for long-term survival. The authors in [9], present a conceptual novel decision-making environment of ISN viability. Moreover, with digital transformation, vast amounts of data can be transferred for improving data-driven decision-making process and increase reactivity of firms to the volatile market demands, since information flows faster within the business. Such factories are called “Smart Factories” and are based on smart technologies, such as process automation, robotics, Internet of Industrial Things, Big Data, Digital Twin, Artificial Intelligence (AI) and so on [8]. A great example of resilience and flexible manufacturing is the Ford and General Motors production line that started producing ventilators for COVID-19 patients [10]. These companies had idle factories and decreased demand in their products, so they started producing personal protective equipment and ventilators in order to assist the United States government in fighting this healthcare crisis. Other innovative approaches that can be applied in Manufacturing are automated material and transportation systems, predictive maintenance tools, AI-based forecasting tools, Virtual and Augmented Reality (VR and AR respectively) and wearable devices, and discrete event simulation models [11, 12]. The above-mentioned solutions can optimize the response time in external changes and create solutions for many problems that can occur. The automated transportation system within a plant can guarantee a 24/7 internal supply of materials and products and at the same time ensure that the human element is protected from accidents within the workplace.

The challenges that this global crisis has created for the manufacturing industries around the globe are primarily the demand shocks and the regulations regarding human interaction. Automotive industry is being forced to shut down factories to ensure the safety of workers, they experience the travel bans and the overload of supply chain. Supply Chain (SC) shocks and adaptations during the COVID-19 pandemic, as well as post-pandemic recoveries, provide incontrovertible evidence for the urgent need for
digital twins for mapping supply networks and ensuring visibility [13].

2.3 Smart Manufacturing

Smart Manufacturing is defined as “a broad category of manufacturing that employs computer-integrated manufacturing, high levels of adaptability and rapid design changes, digital information technology, and more flexible technical workforce training” [14]. Smart Manufacturing can also be defined as “the fully integrated, collaborative manufacturing systems that respond in real time to meet changing demands and conditions in the smart factory, in the supply network, and in customer needs” [15]. This concept includes the ability to quickly alter the production levels based on demand, optimize the supply chain operations, efficiently produce, and recycle materials and other used resources. The idea of smart factory is based on interoperable systems, multi-scale dynamic modelling and simulation, intelligent automation, strong cyber security, and interlinked sensors to ensure real-time and reliable information flow [8]. Some of the key technologies in the Smart Manufacturing movement include big data processing capabilities, industrial connectivity devices and services, and advanced robotics. The review paper in [16] identified the ways in which Smart Manufacturing ecosystems can potentially accelerate smart factory initiatives and a summary of digital technologies deployed in public-health interventions for the COVID-19 outbreak, showing key publications, examples, and resources. Many approaches employ a mix of digital technologies and rely on telecommunications infrastructure and internet access. For instance, machine learning is depicted as a separate branch, despite the fact that it underpins many of the other technologies. The data generated by these technologies is frequently fed into data dashboards. SMS stands for short message service. (Fig. 2).

2.4 Supply Chain Resilience

The coronavirus (COVID-19) outbreak shows that pandemics and epidemics can seriously disrupt supply chains (SC) around the globe. To that, a systematic analysis of the impacts of epidemic outbreaks on SCs guided by a structured literature review and a framework for operations and supply chain management during the COVID-19 pandemic including six perspectives, i.e., adaptation, digitalization, preparedness, recovery, ripple effect, and sustainability is presented in [17]. When supply chains (SC) are exposed to and affected by changes in environmental and operational factors, resilience capabilities enable recovery and adaptation. Digitalization both improves and challenges supply chain resilience (SCR). The development of new paradigms, principles, and models in Supply Chain Management (SCM) in general, and SCR, is influenced by digital technology innovations. Industry 4.0, the Internet of Things (IoT), Big Data analytics, Artificial Intelligence, Advanced tracking and tracing technologies, Wearables, and Additive Manufacturing are all examples of digital technology. As stated in [18], most Fortune 1000 companies, i.e. 94%, are facing disruptions in their supply chain due to COVID-19. The scale of this disruption is a great challenge for supply chain leaders, while the data flow is very fast, and the decision-making process must be performed almost in real-time, to manage the changes imposed by this crisis. The balance between protecting public health and maintaining the global supply chains is crucial and in order to manage the situation, and all the healthcare measures. Consequently, guidelines should be followed in every procedure.

![Fig. 2. The interconnected digital technologies used in response to COVID-19 (Adapted from [16])](image)

The above-mentioned challenges could be described as the travel restrictions, combined with the rigid processes that were used before the pandemic to transport products and the high cost of delivering products from the factory to the final consumer. Potential problems in the supply chain are now obvious and it is very hard for many organizations to adjust their operations, and this is even harder if they do not have sufficient technological infrastructure or if they have obsolete operating systems. The customers today have many expectations, ranging from fast delivery to environmental protection, that companies must abide by to retain customers and fulfill their social responsibility. Finally, the supply chain operations are dependent in the human element and as a result talent shortage in this specific field in combination with the social distancing restrictions create a situation of high volatility [19]. One positive aspect of the COVID-19 era is that the human workforce is being put back in the center of all activities. Thus, ensuring the well-being and productivity of people is crucial for the survival of an organization. In order to address the above-mentioned challenges, businesses and governments should understand how to properly collect and interpret data, in order to drive the decision-making process, as well as manage the demand curve, inventory size, total production capacity and logistics functions through the whole ecosystem and its stakeholders. The market shock that is now observed in the whole world makes it harder to decide which areas to prioritize in the supply chain, so the demand must be segmented, and health institutions should be number one priority to deliver products. At the same time, the whole customer base should
be taken care of and provided with the essential products, dedicated in problem solving and managing the vast volumes of products that people order daily. Finally, supply chain viability (SCV) is a new concept in operations management that is gaining traction. As such, the authors in [9] aim to conceptualize, develop, and validate a SCV measurement scale.

2.6 Novel Technologies Utilized for Covid-19 Response

The real challenge of this pandemic was to design, manufacture and supply countries around the world with huge volumes of the proper diagnostic tools, medical supplies and personal protection equipment in an extremely short period of time, as well as monitor urban movement and transportations globally with limited resources and most importantly secure public health. The production across all industries and around the globe was affected, while the demand and supply were facing phenomenal variations. When lockdowns were implemented in many countries, only essential stores could remain functional, while other retail shops and corporate offices were forced to either shut down, or have their human resources work remotely instead of being in the physical offices. The fight against the pandemic utilized a wide range of novel technologies, for example Machine Learning was used to study huge databases with viral genomes to lay the foundation for our understanding regarding the COVID-19. Through these methods scientists were able to determine the origin and the genetic sequence of the virus [20]. Machine Learning is a subset of AI and is defined as “a computer-based learning achieved by following an algorithm, which operates under a set of instructions or rules, to maximize the chance of a prediction being correct”. The problems that arise from such methods are the patient data privacy and the amount of data needed to have an accurate model. Even though these concerns are valid, the amount of time saved, and the efficiency of such methods is undeniable. Without the necessary computer power and the utilization of novel technologies, people would need many months, or even years, to collect, share, examine and find the patterns that Big Data, Internet of Things and Cloud Technologies can monitor in real-time, and Artificial Intelligence can process with much greater speed and accuracy, in comparison with a team of human workers [21]. Through sensors, mobile phones, security cameras or other sources, data collection is done automatically, and the Internet of Things systems can transfer the data without human involvement to the officials who need real-time information about the progress of the pandemic. Such examples can be found in Boston, where robots are deployed to conduct patient interviews and through sensors, integrated to the robots, measure the respiratory rate and body temperature. Afterwards, data are transferred wirelessly and collected to the Health Care databases for processing. Ultimately, under this framework of operation the contact of healthcare workers with infected individuals is minimized [22].

3. COVID-19 as a catalyst for business models

Governments and health authorities around the world have asked businesses to repurpose their production lines and supply chains due to short supplies in critical equipment such as protective gear for health-care professionals, testing kits and ventilators for patients. As a result, global manufacturers in almost every industry, from fashion to food and beverages, have taken the initiative to shift operations to combat the crisis, by changing the business model of their company. The business model shift of some global companies during the pandemic is presented in Table 1.

Table 1. Manufacturing Industries before and during pandemic [10, 23]

| No | Companies          | Domain               | Before Pandemic   | During Pandemic                      |
|----|--------------------|----------------------|-------------------|-------------------------------------|
| 1  | Ford               | Automotive Industry  | Vehicles          | Modified respirator and ventilation |
| 2  | Tesla-Giga Factory| Automotive Industry  | PV Cells          | Ventilators                         |
| 3  | Airbus             | Automotive Industry  | Aircraft products | Ventilators                         |
| 4  | Mercedes-AMG High Performance Powertrains | Automotive Industry | Formula 1 engines | Continuous positive airway pressure machines |
| 5  | Dyson              | Tech Company         | Vacuum cleaners & hand dryers | Ventilators |

Without a doubt, COVID-19 is transforming the way we live and work. We are entering a “new normal” that will look significantly different from where we are now as a result of the immediate and long-term adjustments being made in response to the virus’s effect on health systems, the economy, and working patterns. Most organizations are now undertaking the Industrial Transformation journey, whether they realize it or not. Industry 4.0 is a broad vision with well-defined frameworks and reference architectures, primarily defined by the integration of physical industrial assets with digital technologies in so-called cyber-physical systems (Fig. 4). Next, a three-part approach is outlined in [24] to be used as a crisis response framework. The three aspects cover the following:

a) **Recover**: keep the lights on during immediate crisis response,

b) **Regroup**: refresh the Digital culture and pivot customer proposition and,

c) **Renew**: seek out new opportunities as we prepare for life in the “new normal”.

This is a resupply of March 2023 as the template used in the publication of the original article contained errors. The content of the article has remained unaffected.
Digital Transformation has been around as a term for many years, although the average company was not yet ready to welcome the new technologies and methods digitalization era introduced. The transition from the automation pyramid to the Industrial Transformation with Industry 4.0 is presented in Fig. 3.

![Fig. 3. From automation pyramid to industrial transformation with Industry 4.0](image)

From simple Entrepreneurial Resource Planning (ERP) software up to end-to-end business solutions, or even having a functional website, a lot of corporations neglected following the trends shaped by new technologies and refused to radically challenge the status quo in the industry. For this reason, when the pandemic reached the doorstep of every single business unit and every country in the world, digital transformation efforts suddenly increased, with many companies turning to e-commerce and all physical stores for retail trade had to stop operating, as instructed by many governments around the globe. The COVID-19 pandemic was considered as an opportunity by many, to evolve and expand their operations by utilizing innovation and technology [25]. Those who did not adapt, eventually will seize to exist because of the strict measures applied in the global market, to manage this healthcare crisis. The key areas for digital transformation, are technology, data, process, and organizational change capability. These four key areas cannot be analyzed as isolated entities, but they must be developed together. The key to all digital transformation activities is the human capital, and as a result all efforts must start with a clear vision and a roadmap to lead the way. COVID-19’s unprecedented supply chain disruption has had serious operational and financial consequences, with planners having to deal with issues such as: 1) demand drops and surges by segment, 2) scarcity of supplies, 3) inventory placement issues, as well as 5) decreased productivity. During the pandemic, Original Equipment Manufacturers (OEMs) and planners were unable to rely on the steady-state models that are at the heart of most existing planning systems. Instead, they've played a critical role for the flow of supply chain data, making decisions based on real-time data.

Moreover, according to [26], the six stages of digital transformation are:

1. **Digitize the Products & Services**
   - Connected Products
   - Pay per Use
   - Predictive usage

2. **Digitize Operations**
   - Customer-centric & standard platforms
   - Agile Approaches to work
   - Anytime, anywhere any device
   - Data Security & Privacy
   - Processes & Systems

3. **Digitize the Organization**
   - Digital Collaboration & Innovation
   - Digital Skills & Virtual Workforce
   - Dynamic Partner Ecosystems
   - Logistics & Supply Chain

4. **Digitize the Customer Experience**
   - Digital Marketing
   - Customer insight
   - Omni-channel
   - Personalization

5. **Digitize Supply Chain 4.0**
   - Full data transparency
   - Autonomous Trucks
   - Predictive Shipping
   - Lights-off Warehouses & AGVs

6. **Digitize the Original Equipment Manufacturer - OEM**
   - Shop Floor Level
   - Sensors & Actuators
   - Management Level
   - ERP - Enterprise Resource Planning
   - MES - Manufacturing Execution System
   - Line Level
   - Process 

Fig. 4. Proposed framework for Digital Transformation
transformation can be categorized as follows:

a) Stage 1: Business as usual,

b) Stage 2: Present and active,

c) Stage 3: Formalized,

d) Stage 4: Strategic,

e) Stage 5: Converged and

f) Stage 6: Innovative and adaptive.

Organizations can become more agile, more responsive to changes in demand, and better able to increase and sustain profitability by automating, standardizing, and globally sourcing processes. Competitiveness is becoming increasingly dependent on human intervention and anticipating fast-changing market developments. Agile practices have been successfully adopted by IT organizations, allowing for faster product development and organizational transformation. Furthermore, because new products and software are developed and implemented at a faster rate, businesses should be able to transform at the same rate and adapt to continuous, abrupt, and rapid change. Additionally, organizations should also enable employees with the flexibility and freedom to work on any device, at any time. Based on the above-mentioned challenges, the digital transformation in action framework is presented in Fig. 4.

5. Conclusion

This paper presents a literature review on the acceleration of the digital transformation triggered by COVID-19 as a catalyst in the utilization of Industry 4.0 technologies as well as a conceptual framework for digital transformation and Small Medium Enterprises (SMEs) business models change. In order to manage a crisis, there must be a scenario identification, to assess the situation and evaluate current management practices. The next step is to develop a strategy and assign responsibilities to the involved parties. Having a crisis management framework before the actual situation is very beneficial for a quick and structured response. The real challenge is the “New Normal” since there can be many positive outcomes when managing a crisis. In this specific instance the COVID-19 pandemic enabled digital transformation for many organizations and led top management to adopt innovative solutions, to preserve their operations. After the pandemic will be finished, it is crucial that organizations continue using these technologies and integrate them to their daily operations. For this reason, future steps will focus on the crisis response framework and a service about altering the current culture and smoothly developing a “New Normal” will be included.

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