Digital Platform and Operator 4.0 Services for Manufacturing Repurposing During COVID19

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Abstract. This paper introduces digital solutions for manufacturing repurposing transformations that address the impact of COVID19 on production operations. The paper outlines how different Industry 4.0 solutions can be combined in a unified platform for manufacturing repurposing. Emphasis is paid on introducing worker and Operator 4.0 related solutions, including tools for plant risk assessment, shifts allocation, context-aware reskilling of employees and remote support processes. The latter are essential elements of a strategy for exploiting automation and Artificial Intelligence (AI) systems during COVID19 times and future healthcare crises.

Keywords: Manufacturing Repurposing, Operator 4.0 Services, Human Centered Services, Sustainability, Human Machine Interaction, COVID19

1 Introduction

1.1 COVID19 and Sustainable Manufacturing

The COVID19 pandemic outbreak has had a severe impact on industrial production [1]. COVID19 impacted the volume of the production, yet it also had other short- and medium-term effects, including: (i) Critical shortages in products like PPE (Personal Protection Equipment) and CCE (Clinical Care Equipment), as a result of supply chain disruptions and a surge in demand for medical products [2]; (ii) Rapid repurposing of supply chains towards confronting disruptions and increasing resilience; (iii) Repurposing capabilities towards new products that were high in demand, such as sanitizers, face masks, and other types of PPE/ CCE [3], [4]; (iv) Impacts on the well-being of the workforce that got infected; (v) A stronger emphasis on supply chain security towards trusted exchange of digital Intellectual Property (IP) (e.g., digital models for new products).

Several manufacturers developed rapid responses to COVID19 disruptions, through proper repurposing of manufacturing operations [5]. Despite these responses, there is still a lack of an integrated framework for addressing the implications of this pandemic and of similar future crises. Most of the developed solutions were ad hoc and focused on the issues faced by each specific factory, rather than framed in a more general platform. This paper introduces a structured, integrated approach for manufacturing repurposing during COVID19 and similar crises that may disrupt production operations. Specifically, the paper specifies a pool of digital solutions that address adverse implications of COVID19. The solutions consider best practices and manufacturing response development guidelines provided by organizations like the World Economic Forum (WEF) and the World Manufacturing Forum (WMF). Furthermore, the paper provides a vision for integrating these technologies in a unified platform. Emphasis is paid on presenting a set of Operator 4.0 related solutions for the continuity of plants and production operations. These include for example solutions for identifying COVID19 risks and for allocating shifts in-line with the skills, health status and availability of employees. The rest of the paper is structured as follows: Section 2 presents four main manufacturing repurposing scenarios that drive the specification of the manufacturing repurposing platform. Section 3 introduces the building blocks of the platform. Section 4 delves into details about the Operator 4.0 related services that ensure business continuity. Section 5 is the concluding section.

2 Manufacturing Repurposing and Response Scenarios

Following paragraphs present four representative manufacturing repurposing transformations. These scenarios stem from our analysis of many manufacturing repurposing cases during the first wave of the COVID19 pandemic.

Scenario 1: Rapid reconfiguration and continuity of production line operation: Following the pandemic outbreak, manufacturers had to re-configure their production lines for two main reasons: (i) Reduction of orders and personnel; (ii) Need for social distancing. In this direction, they had to simulate how their production lines could operate at reduced production capacity and at reduced workforce presence. The above listed capabilities can be provided based on methods and tools for virtual commissioning of safe and secure reconfigured production lines such as digital twins. A pool of Operator 4.0 related services is also required to ensure that flexible, modular, and highly automated production lines can operate with less workers.

Scenario 2: Reliable repurposing of production processes: In this scenario manufacturers had to repurpose their factories to produce different products. This transformation was triggered due to high demand for certain products (e.g., PPE/ CCE), as well as due to the lower demand for their original products. The transformation requires digital capabilities for new product design, engineering, simulation as well as increased manufacturing automation, and effective quality management. Likewise, support for certification in-line with medical standards and normative rules is important for products like PPE/CCE.

Scenario 3: Resilient Smart Supply Networks: Several supply chain reconfigurations took place in response to market barriers (e.g., lack of access to certain suppliers in some regions) or due to political sovereignty reasons (e.g., less reliance in suppliers from certain countries). To address supply chain reconfiguration there is a need for trusted digital supply chain networks that share production capacities (e.g., yield and

production throughput) to match demand with supply. Such supply chains support Manufacturing as a Service business models within a network of trusted companies which share data in a common/shared space.
Scenario 4: Robust on-demand remanufacturing networks: This kind of transformation focuses on the execution of orders through an Additive Manufacturing network. It is based on-demand production networks that share information about their production capabilities, including information on certification levels that they support in cases of medical products. Emphasis is paid on the trusted sharing of IP (e.g., Computer Aided Designs (CAD)) through production networks.

3 Manufacturing Repurposing Platform

3.1 Digital Services for Manufacturing Repurposing

Flexible Production Lines: Flexible Production Lines leverage digital technologies to make their configuration flexibly adaptable to changing needs. Examples of relevant digital components include: (i) **Digital Simulations and Digital Twins** for supporting production flexibility and repurposing (Scenario 1), as well as digital quality management and digital lean manufacturing technologies that support new product design (Scenario 2); and (ii) **Additive Manufacturing solutions**, which boost the flexibility of a production line in the absence of specific materials or parts. This can be useful for several of the presented repurposing scenarios (e.g., Scenarios 1 and 2). It can also enable the provision of on-demand capabilities (Scenario 4).
Flexible and Trusted Supply Chains: Flexible and trusted information sharing across the supply chain boosts the flexibility of supply chain decisions. It also enables smart matching making of supply and demand, which enable manufacturers to take optimal supply chain decisions under constraints. The latter relate to location, time, and cost limitations.
Digital Quality Management (DQM) and Zero-Defect Manufacturing (ZDM): DQM and ZDM services facilitate the rapid discovery of quality issues in the production (e.g., defective products), while empowering relevant remedial actions. Such components are vital for simulating ramp-up times and identifying quality issues during new products design and development (i.e., Scenario 2).
Regulatory and Certification Support: To support regulatory processes there is a need to follow rules, best practices, and regulatory mandates, as part of a multi-level certification framework. The latter provides recommendations for ensuring the compliance of sites, processes, and equipment.
Operator 4.0 Services for Business Continuity: Business continuity must respect applicable restrictions such as COVID19 constraints and related work policies. Services in this direction including plant risk assessment, training, and reskilling resources, COVID19 aware shift allocation strategies, technologies for supporting remote processes, as well as components for financial impact assessment of repurposing scenarios. Such services are important to supporting Scenario 1, yet they are useful for the rest scenarios when factories operate under restrictions.

3.2 Integrated Platform

Table 1. provides a mapping between the four reference scenarios and the Industry 4.0 components and services that were presented in previous paragraphs. The table marks with "M" the services that are mandatory for supporting the scenarios, yet it indicates with an "O" i.e., optional, opportunities for using them in other scenarios.

Table 1. Mapping of Manufacturing Repurposing Scenarios to Industry 4.0 Components

Repurposing Scenarios	Flexible Production Line	Trusted Supply Chains	DQM and ZDM	Regulatory and Certification	Business Continuity Services
Scenario 1	M		O		M
Scenario 2	O	O	M	M	O
Scenario 3		M	O		O
Scenario 4		M	O	O	O

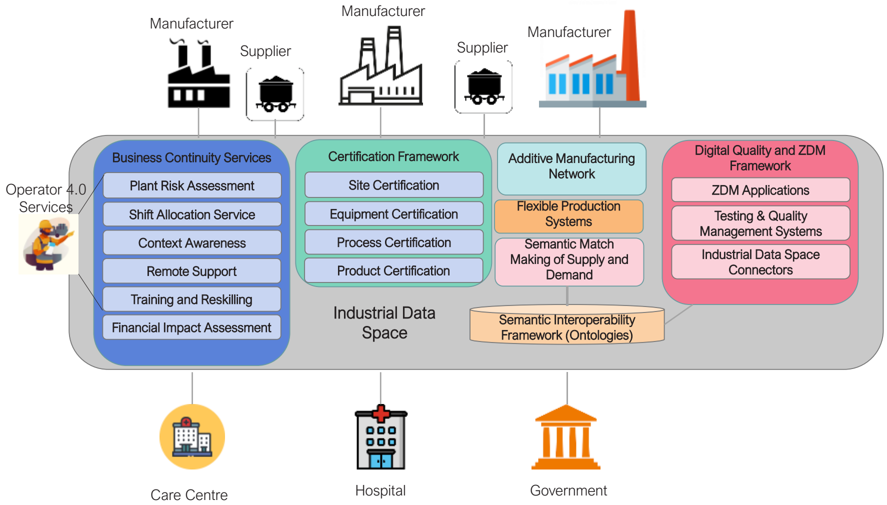

Fig. 1. Integration Concept for Manufacturing Repurposing Transformations

Fig. 1. Illustrates how the above-listed services are integrated in a unified platform, while breaking down some of them in sub-services. For instance, the regulatory compliance and certification services are analyzed to sub-services for site, equipment, process, and product certification. Likewise, the business continuity services include various services such as plant risk assessment, shifts allocation, context awareness, remote support, training, and reskilling. Some of these services address Operator 4.0 needs. Key to the integration of the various services is the industrial data space [6], which enables the trusted exchange of information across the various stakeholders. **Fig. 1.** also illustrates a semantic interoperability framework, which plays a key role

in ensuring that data from different sources adhere to common semantics. This is important to supporting intelligent supply and demand matching for Scenario 2.

4 Operator 4.0 Services for Crises Management

4.1 (COVID19) Plant Risk Assessment: Identifying Operator 4.0 Risks

Manufacturers must identify activities that ease the spreading of the virus and plan for remedial actions to minimize the likelihood of spreading. To this end, they must establish risk assessment processes aimed at: (i) **Identifying and documenting risk factors** that could cause damage to the workforce and the enterprise. These include risk factors concerning the health and safety of the employees, yet there are also other risks that concern supply chain operations and contractors; (ii) **Grading the risks** through assessing their likelihood of occurrence and their potential impact on the enterprise. This is important for prioritizing remedial actions; (iii) **Specifying mitigation actions** for eliminating or controlling the risks. Typical risk control actions are the implementation of social distancing measures, the reengineering of production processes towards a safer direction (e.g., reduce sharing of tools), the implementation of staggering shifts, the exploitation of PPE for workers, and the provision of hand-washing facilities. The risk assessment tool of our platform leverages best practices and recommendations specified by health and safety organizations in Europe (e.g., the Health and Safety Executive (HSE) governmental organization in the UK). They also specify mitigation actions such as: (i) **Workplace social distancing**; (ii) **Reduction of physical activities** that can lead to infection (e.g., sharing of tools across workers); (iii) **Support for Remote Work**; (iv) **Special measures for groups of people** that are at higher risk if infected. When compared to the COVID19 risk assessment forms used by many factories, our risk assessment tool provides the following added-value: (i) **On-line data collection and sharing** with other modules that support manufacturing repurposing; (ii) **Provision of actionable recommendations** for each main risk.

4.2 Operator 4.0 Shifts Allocation

Given COVID19 restrictions, ensuring an adequate number of employees with proper skills in the shopfloor is challenging. In this context, shifts allocation must identify mitigation actions that could alleviate production continuity challenges. In this direction, our solution considers the following functionalities: (i) **Assessing employee skillsets**, to identifying shortages in certain skills; (ii) **Identification of retraining requirements**, towards mitigating shift allocation and skills shortage; (iii) **Ensuring conflict avoidance** towards supporting production continuity; (iv) **Management of leaves and time-off**, considering applicable restrictions; (v) **Management of shift coverage**, including scheduling of positions based on the available skills; (vi) **Support for limited capacity operation**, for reasons such as physical distancing rules and unplanned absences due to infections. Baseline shift allocation functionalities are provided by mainstream ERP (Enterprise Resource Planning) systems such as SAP (i.e., SAP's Time and Attendance Management), and Microsoft Navision (i.e., Resources Allocation module). Furthermore, there are various stand-alone tools (e.g., Connectteam (https://connecteam.com/), mHelpDesk (https://www.mhelpdesk.com), Shiftboard (https://www.shiftboard.com), Staffjoy (https://www.shiftboard.com)) that solve the shift allocation problem. Nevertheless, these tools fall short when it comes to supporting allocations in the light of COVID19. Most of them do not provide support for defining continuity between departments or defining department areas, so that employees' shifts can be optimized in the light of distancing restrictions. Based on these considerations, our tailored shift allocation services assign available staff workers to shifts per sector in the facility.

To achieve maximum isolation between staff workers, our tool divides them into groups. Each group is assigned to a unique shift in a specific sector of the department. Employees can work in different sectors during their shift. Each shift is configurable (i.e., 8-hour by default with 2-3 daily shifts per sector). Personnel is assigned to shifts in each sector according to their profession and skills, i.e., employees that fit the sector's required profession have higher cardinality to be selected. Shift allocation is applied every two weeks. To balance the activities, each group of employees rotate their shift every week. To achieve maximum productivity per sector, a minimum number of working hours is set to our solution model with respect to the maximum contractual number of working hours per week. The key objective function of the solution is to minimize the sum of the deviations from the contractual number of working hours for each worker. Deviations apply additional costs to the organization: Positive deviations will lead to extra costs, while negative ones lead to missing hours in an employee's schedule that need to be paid. The solution model follows the MILP (Mixed-Integer Linear Programming) formulation. Linear dynamic programming solvers are applied to define the optimal solution to the shift allocation problem. The main constraints are reflected in the following equations.

$$\mathbf{min}\,\boldsymbol{\Delta}: \sum_{e \in E} \sum_{w \in W} \boldsymbol{\delta}_{ew}^{-} + \boldsymbol{\delta}_{ew}^{+} \tag{1}$$

$$\mathbf{s.t.} \sum_{\alpha \in A} \sum_{s \in S} \boldsymbol{x}_{se}^{wa} = \mathbf{1} \tag{2}$$

$$\sum_{\alpha \in A} \sum_{w \in E} \boldsymbol{x}_{se}^{wa} = \mathbf{1} \tag{3}$$

$$\sum_{e \in E} \boldsymbol{y}_{se}^{wa} \geq \boldsymbol{\tau}_{sa} \tag{4}$$

$$\sum_{a \in A} \sum_{s \in S} \boldsymbol{y}_{se}^{wa} + \boldsymbol{\delta}_{ew}^{-} - \boldsymbol{\delta}_{ew}^{+} = \boldsymbol{h}_{e}^{max} \tag{5}$$

$$\boldsymbol{x}_{se}^{wa} \leq \boldsymbol{c}_{ea} \tag{6}$$

The six equations [7] are interpreted as follows: (1) The objective function that needs to be minimized. It minimizes the total deviation between the amount of weekly contractual hours of each worker and the actual working hours; (2) Each employee must be weekly assigned to exactly one shift and one sector (A=>set of sectors, s=>set of shifts); (3) Each employee must work in exactly one sector per shift (A=>set of employees); (4) Ensures that the working hours for every shift in each sector are respected; (5) Ensures that the actual working hours per week for a specific employee after subtracting the deviations must be equal to the contractual hours; (6) Ensures that each employee that is selected for a specific shift is aligned with the sectors required qualifications (C_{ea} ε {0,1}), where 1 represents that an employee is qualified and 0 represents that the employee does not fill the requested qualifications for a specific sector. The optimization problem is solved using open-source Integer optimization solvers. For this purpose, open source software Google OR-Tools [8] is used for modeling and solving the MILP equations. The data model that supports the provision of the service is depicted in **Fig. 2** below.

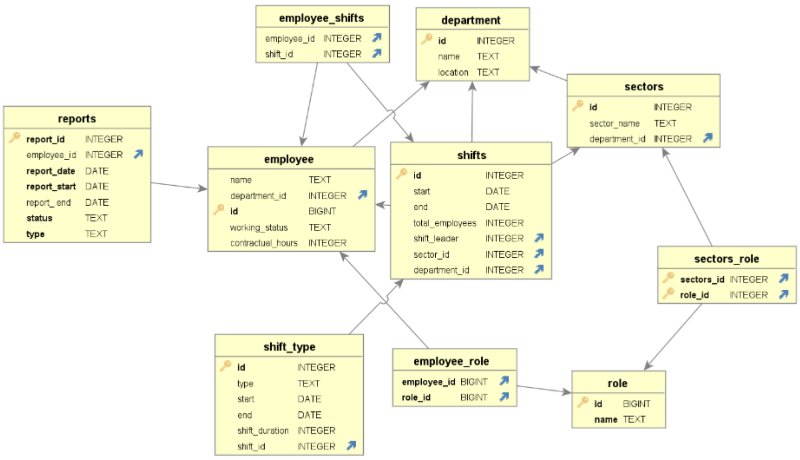

Fig. 2. Outline of the Database Model Supporting the Shifts Allocation Service

MILP problem formulation will lead to deterministic solutions, emergency situations are handled by each solution by assigning emergency personnel in standby to operate the production line of each sector during a shift in case of contagious event.

Each employee is described by the **employee** table. An employee can have multiple roles and is member of a specific department. Also, contractual working hours and his availability to work (working_status) are also persisted. An employee can be assigned to multiple shifts and each shift belongs to a specific sector, **employee_role, employee_shifts** are index tables defining many to many relationships between employee and roles as long as employees and shifts. Each shift is described by the **shift** table, each shift belongs to a sector and includes multiple employees that need to work between timestamps defined by **start** and **end** attributes. Emergency employees are scheduled in each shift so that they can replace colleges in case of infection. All departments consist of multiple sectors and require multiple qualifications in terms of roles from employees in order to be assigned to relative shifts. The **sector** table describes all sectors per department and **sector_role** index table defines many to many relationships between sectors and roles required for each of them during the production stages. Finally, each employee can provide reports regarding his health status and his availability to participate in his assigned shift. All information in each report is included in **reports** table.

In case of an infection during a shift, all employees that were working in the same group are isolated as part of the contact tracing procedure, until they receive a negative test. In the meanwhile, the facility operator decides if the shift will be operated by emergency staff assigned by the MILP formulation solution, or the production line can be adjusted to bypass the sector that the event took place.

4.3 Situational Awareness

COVID19 leads to volatile and dynamic manufacturing contexts. Therefore, manufacturing enterprises and their employees can greatly benefit from (near) real-time monitoring of business continuity parameters [9]. In this direction, trusted data spaces that collect and consolidate information from different sources can provide value as shown in **Fig. 3**. The data of these spaces are analyzed and exploited to improve the resilience of the monitored digital infrastructures, through the construction of Situational Awareness (SA). SA pictures (i.e., snapshots) provide an understanding of relevant events and offer the ability to observe the state of the systems in an integrated manner. Manufacturing workers and the business management can therefore confront these pictures to objectives, constraints, and acceptable risks.

The proposed modular and incremental approach to Situation Awareness design is grounded on a series of data analysis tools, based on (big) data analytics techniques, Artificial Intelligence, graph intelligence and correlation of information. To this end innovative multi-level situational awareness models may be adopted, to include in an integrated way information relating to all the relevant aspects for the integrated assessment of the digital infrastructures underlying the monitored manufacturing businesses. This information model constitutes the enabling layer to determine, analyze and manage the risk, at the different levels and components of the monitored infrastructures intended as a complex System of Systems.

Furthermore, as part of a situational awareness creation service, for the continuous monitoring of the resilience and business indicators of the monitored ecosystem, techniques and solutions will be integrated in order to obtain an effective early warning in the event of possible accidents or threats. In this sense, a "focusing" and "zooming" mechanism and related intelligent functions will be defined and designed to focus on specific entities. Therefore, this module implements a multi-level surveillance and situational awareness approach in which the monitoring services will be “activated” more on specific areas and data sources / flows according with the perceived level of risks and received high-level signals.

Any manufacturing business ecosystem is, in fact, characterized by multiple components and subsystems highly interconnected from a technical, technological, functional, organizational and process point of view. This interconnection turns into dependencies at the level of vulnerability that can generate cascading threats and accidents (think about the effect of a lack of raw material in a supplier that certainly impacts a multiplicity of its customers). Analysis of the cascading effects between the various elements of the same system or the same business manufacturing ecosystem can be conducted to assess the status and performance whole business ecosystem.

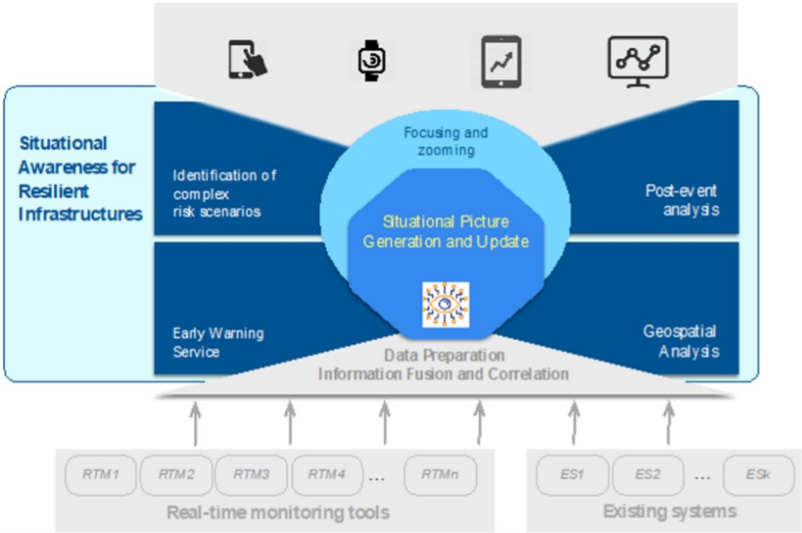

Fig. 3. Situational Awareness Solution Architecture

4.4 Remote Support

COVID19 has added new requirements towards remote reprogramming and support, which eliminates the contact between the operators and ensures the security distances. Work allocation in the factory layout must be organized in the virtual environment, keeping security distances between plant operators, and maximizing productivity. In a limited mobility environment, the virtual environment must provide interactive support through VR (Virtual Reality) and AR (Augmented Reality) technologies. The latter allow the operators to be trained in new production requirements and to safely execute everyday tasks such as asset monitoring, field services and repairs.

5 Conclusions

This paper has specified digital services that alleviate challenges faced by manufacturers during COVID19. It has also illustrated the integration of these services in a unified platform. The latter includes Operator 4.0 related services aimed at ensuring engagement of workers with the proper skills in the plant operations, despite COVID19 restrictions. The presented platform could become a blueprint for manufacturing repurposing in cases of large-scale disruptions to production operations. In this direction, we are currently developing the services of the platform, which we plan to validate in two manufacturing plants that produce PPE/CCE products. The blueprint design and selected components will be made available through the Digital Factory Alliance (DFA) (https://digitalfactoryalliance.eu/).

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