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COVID-19 Effects on Distributed Manufacturing

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Abstract: The disruptive event of the COVID-19 pandemic appearing in 2020 changed the rules of how international supply chains and businesses perform. The pandemic took most of the countries and organisations by surprise, with the tragic consequences of 203 million infections and almost 4.5 million deaths worldwide until August 2021. This paper deals with the consequences of the pandemic relating to international distributed manufacturing. Generally, the risks and challenges that arise in this crisis are manifold and range from immediate health risks, isolation risks to the disruptive changes in the supply chain and manufacturing setups.

Resilience, redundancy, and flexibility are the main factors of robustness that play an important role in this crisis management. Building up robustness and resilience is proposed by applying corrective and preparative action for a wide range of production factors (people, material, processes, supply chain etc.) and a variety of risk classes (health, isolation, lockdown).

Keywords: distributed manufacturing pandemic covid-19 crisis management mitigation resilience

1. INTRODUCTION

Distributed engineering and manufacturing represent an integral part of today’s international economic and business relations. The model represents one of the cornerstones of the economic development throughout the last centuries, not limited to industrial economies in Europe and North America, but also the rest of the world. This paper focuses on how to cope with the management challenges that distributed manufacturing organizations are currently facing.

Fig. 1. COVID-19 cases (WHO, https://covid19.who.int/)

Firstly, we will briefly introduce the challenges coming from distributed manufacturing. Distributed manufacturing organisations face risks regardless of the current pandemic. Manufacturing is a very complex endeavour, and risks are numerous: Markets conditions and demand may shift, workforce with related cost might change over time, supply chain condition might change. We will then deal with how to mitigate the risks that are related to and coming from the current pandemic with corrective and preventive actions. For this purpose, the paper will introduce risk categories and risk mitigation. This includes health risks, that are concerning people’s well-being; isolation risks that relate to the local organisation unit, as well as lockdown risks that deal with how the organisational units deal with each other (network of companies, sites, or organisations). The risks and mitigation action will then be related to production factors (people, products, equipment, information technology) to come up with a basic framework for coping with these issues. Factors like the size of the organisation or the effort with which the mitigation can take place are presented. The severity and effort to go with the mitigation action is included in the analysis. The paper concludes with reflections and an outlook.

2. DISTRIBUTED MANUFACTURING (DM)

Distributed manufacturing (DM) is understood as the technology, systems and strategies that organize the manufacturing with regards to location and scale (Durach et al. 2017). This includes decisions on how to set up and scale the organization of the manufacturing process in different locations. In intermediate steps, finished or half-finished products (components) can then be brought together in further location where they are further processed and assembled. This introduces a key element to distributed manufacturing. DM therefore requires a highly sophisticated logistics system to bring the required assemblies together at the right time, in the right place with the required quality and the needed quantity. The logistics function then extends further to the customers locations for marketing and sales (Graham et al. 2020). These processes were initially located at the same site, even though most of the information was only available in analogue form (design drawings, charts, instructions). With the rise and stepwise introduction of modern digital data processing systems in the early 1960s this obstacle could be circumvented, and distribution was easier to achieve.

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Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2021.10.414
The first applications were Computer Aided Design (CAD), planning tools, and simple database systems for storing information. Computer Integrated Manufacturing (CIM) summarizes these functions and describes the organizational integration thereof: Computer Aided Design (CAD), Computer Aided Manufacturing (CAM) with scheduling and process control (PC) as well as the business functions such as billing, costing with the respective interfaces into the accounting and sales functions. All these functions in manufacturing, manufacturing control, planning, design as well as in administration and sales generate a considerable amount of data of various type (drawings, bill of materials, production plans, work instructions). In addition, manufacturing also generates a lot of required data for pre- and post-manufacturing phases such as quality documents, costing information, billing data, and customer related data.

All these data are stored, processed, and sometimes integrated into upstream systems as well (Kappel et al. 1994). Industry 4.0 represents the latest development in manufacturing and can be described as ‘the intelligent networking of machines and processes for industry with the help of information and communication technology’ (Chen et al. 2018, Epple 2016, Imkamp 2016, Schwab 2016).

2.1 Management challenges & production factors

Plenty definitions about management and the related tasks and responsibilities can be found and management paradigms are abundant (Gutenberg 1966, Locke 1982; Schmid 2000; Steven 2000; Wilkinson et al. 2017). However, on the operational level it always comes down to running and shaping organisations. Management is defined as the task of setting up an administration, setting up targets, controlling and developing resources to fulfil the company targets (Drucker 2008). Management is therefore a function on various levels within the organisation.

Manufacturing deals with the production of tangible outcomes, ‘real’ things. As a contrast to the new (IT) technologies, it results in outcomes with physical characteristics; ‘things’ are produced. In the case of distributed manufacturing (DM), the production process is performed in different locations under special conditions and control. As the production deals with material outcomes, the handling, transport, and storage requires special focus by the management as well. Manufacturing management deals with the planning, scheduling, and controlling of manufacturing processes. It guarantees the efficient layout of production, the smooth transport flow of material and the availability of the necessary workforce in the needed quality and required quantity. Further tasks and responsibilities are purchasing, operational safety and quality management. In operations respect this includes organizing the production means such as employees, products, material, equipment, and IT (see Guttenberg 1966; Locke 1982). Along these factors, the following needs attention when dealing with the distributed manufacturing:

People make up one of the main productivity elements in any organisation (administration and factory floor) and thus represent a mayor production factor. Products (or semi-finished products) are the tangible outcome of the manufacturing process. The process is for making the product is essential any manufacturing related issues. The product design strongly determines the manufacturing process. Data will include the localization of material data from localized suppliers or simply if the material only available at certain qualities in a region.

Material, base, or intermediate materials (assemblies) are the basis for any manufacturing process, availability and quality is essential to the outcomes. The availability of supplies sources locally plays into this to a great extent. Therefore, building up suppliers in the local manufacturing site region is crucial for the success, any change in sourcing material provenance is also a question of a qualified supplier base.

Equipment for the manufacturing is critical to produce an outcome. Equipment is related to the technical product design which in turn determines the design of the production site. The latter is a long-term issue given time and capital expenditure it takes to set up production sites.

Information technology is essential in 21st century manufacturing, the development depicted earlier shows this development. IT is covering all equipment, networking on site and between sites, and telecommunication; both for administration and for production facilities (Epple 2016).

Quality management is an essential tool for creating customer satisfaction, increasing efficiency, and thus ensuring profitability. The quality management settings are mostly mandatory in all the production sites, details may vary along the lines where material availability and client requirements are mandating adaptations.

Partners are a resource and factor that is often not considered as a risk item. Firstly, communication must be kept up with any related parties. The risk mitigation of the partners (e.g., material suppliers, service companies) might have profound effects on the action planned in the first place. It must be kept in mind that partners in this sense also include local service providers and related local government agencies.

2.2 COVID-19 risks & mitigation action

Any kind of pandemic has three main organisational effects we are experiencing right now. We now focus on the COVID-19 specifics. The risks related to people are presented, the facilities and sites as well as between sites, respectively.

Health management, medical (people challenges)

The current development shows that the solution thereof must be one of the primary tasks of the management. Companies, with all their organisations and suborganisations from headquarter to manufacturing site must be protected to contain the virus and curb infections. This includes all possible health measures that must be taken as suggested by most of the relevant health authorities. Social or physical distancing (1-2 meters distance, avoiding crowds), wearing face masks when in public (or at the workplace), increase hygienic measures such as hand hygienic and other disinfection measures. The
focus in this risk group is clearly on the people’s well-being and their health protection. The World Health Organisation (WHO, www.who.int) is constantly reviewing the suggestions on health-related issues and the medical action required, on a country level these actions might be further detailed.

**Isolation management, physical (site challenges)**

Part of the physical distancing measures mean that persons or groups of persons must be isolated to minimize infections. A consequence is that management must deal with these issues be introducing new (extended) shift models, the establishment of cohorts (group of employees that physically do not meet each other anymore. Home office for administration staff has been introduced earlier as an incentive for the workforce. However, the recent developments make it necessary, and management must deal with this by introducing the administrative but also the technical prerequisite to implement these options. Employment contracts might need to be adapted, IT-equipment must be available, software access and data lines must be available. This risk category focuses on the consequences of the local (manufacturing) site and the issues that must be resolved locally.

**Lockdown restrictions (global challenges)**

The more global issues that arise from the COVID-19 risks is mainly concerning restrictions or actions that are coming from the lockdown restrictions that have been imposed in several qualities. The lockdown has been a measure to implement the isolation requirements mentioned above. This can be done on various levels of implementation and mostly on a regional (country) basis. Mostly, the regulations have been introduced covering the following measures: **Closing** non-essential businesses (restaurants, flower-shops etc.), the basic idea is to reduce contacts in public. **Restriction** to businesses only in the essential businesses to keep up basic needs and the infrastructure such as food, pharmacies, phone providers **Curfew** measures to limit the number of people to their home locations. People are only allowed to leave their homes for work-related or health matters.

The handling of the counter measures depends on the political systems as well. Requirements such as full contact tracing with mandatory phone apps make sense from the epidemiological standpoint, however the implementation of such action in liberal democracies is more difficult than in more authoritarian regimes, all with different outcomes. The measures are introduced on a country-to-country basis, we refer to the WHO for the latest updates and developments.

For operative reasons we now introduce ‘measures of disturbances’ indicating the level of impact the risk measures represent. The categorization is based on a simple ABC analysis related to the level of disturbance that the measures are implicating (Ultsch 2002). Low or short-term disturbance \((L)\) can be mitigated rather quickly with relatively and reasonably low cost involved. Medium disturbance \((M)\) requires a longer transition time of 3-6 months and comes with a higher than usual cost tag. Given the potential duration of the disturbances, these costs can mount up considerably. High disturbances \((H)\) are caused by risks that need considerable efforts for change. In the latter case we look at long-term projects (> 12 months) that will usually require extraordinary budgetary requests which would consequently mostly need company board involvement.

### 2.3 Corrective & preventive actions, factors of robustness

We are now combining the risks and actions and come up with counter measures that can be used to when facing COVID-19 related risks. We see the risk mitigation efforts can be seen as pro-active measures whereas the counter measures are the outcome of immediate reaction to a risk.

Previously, the reduction of cost or the minimization of throughput times has been set as the priority when looking at technical product designs and factory design. Nowadays, with the restrictions in place that were mentioned above the focus shifts to redesign processes and organisations pro-actively. Earlier research has been focussing on the redistribution of production capabilities and product scopes to find new opportunities in the market(s) (see Kumar et.al. 2020), or to predict the supply chain related consequences of a pandemic outbreak (Ivanov 2000).

In this paper we are targeting these factors of robustness that help to stabilize any (production) system in case of disruption: **resilience**, **redundancy**, and **flexibility**.

Organisations and their processes must become more resilient. **Resilience** describes the ability of a company to fulfil its tasks and responsibilities even if some of the infrastructural or environmental condition fail or are deeply disturbed. The main concern is the robustness of the processes when disturbed. The organisation must be able to recover from failures, catastrophes, or abrupt changes in the environment. One of the infrastructural conditions is the freedom of movements for goods and personal. COVID-19 is certainly affecting this. Making processes and organisations more robust is challenging and sometimes conflicting other tasks and targets. Consider the production with base material that can be sourced from different parts in the world, or even locally. Clearly having locally sourced material is more resilient than having to rely on products that must be transported under difficult conditions.

**Redundancy** represents a similar measure. It is a concept that opens viable alternatives in case primary solution patterns fail. Consider the availability of a stable data line to connect to other locations or the world in general. Resilience can be achieved with installing a performant backup line that can be of service in case the primary fails. Moreover, the technology must be different to prevent the backup solution relying on the same technology as the primary solution. However, this solution is mostly conflicting with the financial targets that must be considered. Having backup solutions in place usually increases the cost. Reducing redundancy and increasing resilience can be conflicting tasks and management has to set the priorities in this case.

**Flexibility** is a further available measure. When dealing with the disruptions we are currently facing, we are required to
assert much more flexibly that in the usual standard situation. In general, non-pandemic, situation we focussed on streamlining processes and businesses. Processes were optimized in re-engineering projects and focused on the optimization of the tasks. To a considerable extent the reduction focussed on reducing material or reducing (unused) time. The reduction of idle times in quality management lead to a lean process and established a whole new view on how production is done. The optimization of the material usage and availability lead to the reduction of (internal) stock and introduced optimized supply chain organisations that synchronized material availability along production lines.

Businesses facing the disruptions caused by the pandemic must rethink all these paradigms. The current difficulties of getting goods, services, and people at the right time to the right place will inevitably stretch the ‘optimized’ time schedules that were assumed in earlier process schedules. Having (emergency) stock in place or switching to locally available purchasing will help to regain resilience.

But these initiatives come with a price attached. The process optimizations earlier were partly driven by cost reduction programs. Reintroducing slack and stock are flexible measures to regain resilience. These counter measures certainly have consequences and will have a considerable influence on the production cost.

Again, the efforts that have been taken in optimizing the supply and the production chains were based on the optimization paradigm of streamlining the processes and reducing waste of any kind, thus resulting in reduced cost. In case of reversing this via risk mitigation, the cost will increase for most of the corrective and preventive actions taken.

3. RISK MITIGATION

We now introduce the measures that can be applied to increase resilience, redundancy, and flexibility in the field of distributed manufacturing. For further analysis and a clearer view, we introduce the company size and the depth of the measures.

Furthermore, the depth and timeliness and the effort required to implement the corrective actions is of interest. With shallow measures immediate action with an implementation time of 3-6 months is assumed. Short- or medium-term action are for example changes in internal regulations (travel), cohorting of workforce, or partial renegotiation of purchasing contracts. Deep activities and preventive actions on the contrary represent action that is considered rather long-term. These actions could also result in moving production sites or the broad introduction of Industry 4.0 related technologies such as integrated databases and supply chain integration (see Schwab 2016; Imkamp 2016).

In our model, deep and shallow measures relate to the time and ease of implementation but also to the related cost that are involved. Especially the medium (M) and high (H) risks lead to a substantial increase of operating cost and if required a considerable capital expenditure.

In the following this paper describes how to extend and combine the general tasks described earlier with the special tasks that can be performed to face the pandemic. Actions along the dimensions and the risk mitigation are proposed.

| Factors                           | Health (people)                                                                 | Isolation (res)                                                                 | Lockdown (global)                                                                 |
|----------------------------------|--------------------------------------------------------------------------------|--------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| People                           | COVID-19 testing (L)                                                             | Coloring (L)                                                                   | Build up redundancies, multisite (M)                                              |
|                                  | hygienes (L)                                                                     | Video conferencing (L)                                                         | Short-term and long-term replacement (M)                                            |
|                                  | social distancing (L)                                                           | Hotel office (L)                                                               | (M)                                                                              |
|                                  |                                                                                | Temporary placement of personnel (M)                                          |                                                                                  |
| Products and process management  | COVID-19 testing (L)                                                             | Localization of production                                                       | Prepare for retreating to group members (M)                                       |
|                                  | hygienes (L)                                                                     | and managing hygiene                                                              | Increase localization (M) H                                                      |
|                                  | social distancing (L)                                                           | Adaptation of PLM (M)                                                         | Keep PLM systems updated and coherent in case of changes (M H)                   |
| Supply Chain, Material           | COVID-19 testing (L)                                                             | Building stocks for basic material (M)                                         |                                                                                  |
|                                  | hygienes (L)                                                                     | Pre-order half-finished                                                             |                                                                                  |
|                                  | social distancing (L)                                                           | goods, stock up (M)                                                           |                                                                                  |
|                                  |                                                                                | (M)                                                                             |                                                                                  |
| Equipment, production concepts   | COVID-19 testing (L)                                                             | Schedule pre-emptive maintenance (M)                                           | Pre-empted finished goods to internal and external customer (M)                   |
|                                  | hygienes (L)                                                                     | Local machinery redundancy (M)                                                  | Get new local suppliers (M) H                                                   |
|                                  | social distancing (L)                                                           |                                                                                  | Provide the client requirements on their stock licenses (M)                      |
|                                  |                                                                                |                                                                                  |                                                                                  |
| Information Technology           | Contact maintenance teams (L)                                                    | Remote administration (L)                                                       |                                                                                  |
|                                  | (IT)                                                                            | LAN administration (L)                                                         | WAM supermarket (L)                                                              |
|                                  |                                                                                | WAM, change routing options (M)                                                 |                                                                                  |
| Quality Management               | COVID-19 testing (L)                                                             | QM personal coloring (M)                                                       | Reengineer take-over procedures for remote quality checks (M)                   |
|                                  | hygienes (L)                                                                     |                                                                                |                                                                                  |
|                                  | social distancing (L)                                                           | Introduce videoconferencing for externals (L)                                  |                                                                                  |
|                                  |                                                                                | Engage in local governmental tasks in order to facilitate (M)                   |
|                                  |                                                                                | long-term factory planning (M)                                                  |                                                                                  |
| Partners, Communication          | Keep up information flow for potential visitors about risks and solutions (L)   |                                                                                |                                                                                  |
|                                  |                                                                                | Introduce videoconferencing for externals (L)                                  |                                                                                  |
|                                  |                                                                                | Engage in local governmental tasks in order to facilitate (M)                   |
|                                  |                                                                                | long-term factory planning (M)                                                  |                                                                                  |
|                                  |                                                                                | Reengineer take-over procedures for remote quality checks (M)                   |                                                                                  |

Fig. 2. COVID-19, framework of risk mitigation action

The table is made up as follows. The columns cover the risk factors that may occur in the before mentioned categories, health, isolation, lockdown. The rows contain the various production and management factors that were proposed above (workforce, products, supply chain and materials, equipment, IT, quality management and partners.

Certainly, these mitigation actions make sense when facing the immediate threats. Proactively, it is also valuable for the reduction of the arising risks. The effects are decreased or in some cases even eliminated.

This paper covers an analysis of these issues and proposes suggestions for the mitigation of the COVID-19 risks. The outcome and the lessons learnt from this ongoing pandemic are manifold. Related to manufacturing they are rather simple and straightforward. In the recent years, companies have optimized systems, processes, and organisations to a great and necessary extent. The engineering and re-engineering profession as well as quality management eliminated slack (lead times, buffers, excess stock levels or alike), waste (material optimization, processes), and excess of time out of the processes and procedures (product and process engineering).

Supply chain optimization added to the success by reducing the intermediary time between (distributed) processing even more. Processes became faster, cheaper, and optimized to a great extent. However, consequently, the resilience, robustness, and flexibility decreased. The supply chains became more vulnerable and more inclined to interruptions and delays, with disruptive consequences as we painfully experience throughout this pandemic.

The presented analysis shows that some of the actions are short-term with a speedier time frame and presumably lower
cost factor, while others are rather long-term with higher cost attached. A further differentiation comes along the dimension of company size. Some companies are limited in scale and thus have less financial leeway for such large-scale change. However, this disadvantage can also turn into an advantage given the resistance of change sometimes inherent to large organisations.

4. CONCLUSION

In a nutshell, the risk mitigating actions to cover disruptive events such as the COVID-19 crises are summarized as follows:

*Increase resilience and robustness* by adding viable alternatives to supply countries, transportation routes, material (single) availability.

*Stock levels* are a common and reliable means to gain flexibility when dealing with supply chain problems. As helpful as it is in the short and medium term it must be pointed out that we are looking at considerable cost increases when increasing stock levels, both profitability and liquidity of financial assets are concerned.

*Strengthen the material base* by adding more qualified suppliers (from different regions), re-engineer your products to allow for more material varieties.

*Product redesign* as in one of the examples above is the option with the most thorough consequences, it has the potential to change the setup of the whole business.

*Production setups* must be kept as flexible as possible to be able to deal with a variety of materials and sub-assemblies.

*Protect workforces* by adding redundant setups in the locations. Also, the deployment options of the workforce must be more flexible, training and qualification programs can help to get this done.

*Cost considerations* must obviously be kept in mind when dealing with changes of a certain scope. In particular, building up stock to get more resilient process supply chains can be tricky and result in a considerable increase of operating cost. Similarly, the move of production sites or the redesign of products usually requires heavy investments and thus higher production cost.

Adding more *robustness, resilience, and flexibility* in supply chains and processes represents a fundamental mitigation task. Companies that do not tackle this task will find themselves in a position where their clients might move on to other suppliers. They must react and take the changes into effect; any other action makes them difficult to compete in the markets. In addition, the next crisis or pandemic might just be around the corner.

The *competitive advantage* resulting from the risk mitigation is not only restricted to companies and organizations. Governments, local or regional, are as well in competition. In the course of the pandemic we see some countries that take a rather neglectful approach when implementing actions against the pandemic.

All the suggested corrective actions are posterior measures to the event of a crisis. However, it can be used in further scenarios as preventive measures. Firstly, when industrializing new products and setting up new industrial sites, the analysis delivers as beneficial and will provide insight in the way to come up with more resilient and flexible business setups. Secondly, even without an actual imminent threat the analysis can be deploy an analysis of weakening points of any organisation, either for the preparation of the next pandemic or any other threat of disruption.

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