**Appendix E: Opportunities**

***Hedged Sourcing Strategy (Demand Risks)***

The integration of AM with CM as a hedging strategy has also been recently investigated in the medical sector. Indeed, AM can provide a buffer to address volatile demand, representing an emergency production setup that can serve as a backup system (Wang *et al.*, 2021): as suggested by Meyer *et al.* (2022c, p.19) a “*smart-order management*” strategy can be adopted, where CM can be used when the demand is stable (helping reduce costs) and it can “*proactively switch to AM when necessary to avoid stock-outs*”.

In conclusion, we can derive the following proposition:

***Proposition O1***: Integrating conventional manufacturing with AM can minimize demand-related supply chain risks.

***Hedged Sourcing Strategy (Supply Risks)***

Adopting a hedged sourcing strategy is reported to minimize also supply-related risks: “*using AM as a hedged source of supply to traditional supply sources increases the overall resilience of the supply system*” (Meyer *et al.* 2022b). This is confirmed by Meyer *et al.* (2022a, p.9), who concluded that not only “*hedging provides a valid sourcing alternative for procurement organisations*”, but also that hedging “*seems to minimise supply risk*” and that it “*could help build resilient supply chains*”.

In conclusion, we can derive the following proposition:

***Proposition O2***: Integrating conventional manufacturing and AM can minimize supply-related supply chain risks.

***Resilient Supply Chain***

The COVID-19 pandemic has shown how the need for resilient supply chains is of vital importance, especially in the medical sector (Xiong *et al.*, 2021; Asokan *et al.*, 2022; Shen and Sun, 2023). AM has emerged as a viable solution to guarantee supply chain resilience, with Peron *et al.* (2022, p.131) stating that, thanks to its ability to produce parts on-demand and close to the point of use, *“AM has shown to be very effective in guaranteeing the restoration and reconstruction of the SC, especially in the production of medical equipment (e.g., face masks, valves for respirators, etc.)*”.

In conclusion, we can derive the following proposition:

***Proposition O3***: Adopting AM can reduce and/or mitigate the impact of supply chain disruptions since it allows to produce on demand and close to the point of use.

***Environmental Sustainability***

As discussed above, AM has the potential to revolutionize supply chains, especially the transportation phase, thanks to its on-demand and decentralized production. According to Calignano and Mercurio (2023, p.4), in fact, *“the use of AM … offers the opportunity to have decentralized structures located close to the consumers”* with reduced transportation needs. Hence, AM allows for *“shorter, simpler value chains”* with tremendous benefits for sustainability since such decentralized production reduces *“the environmental effect of logistics significantly”* (Javaid *et al.*, 2021, p.320).

In conclusion, we can derive the following proposition:

***Proposition O4***: The possibility provided by AM to produce parts close to the point of use reduces the environmental footprint of the supply chain since shorter transportation routes are required.

***Reduced Need for Employees***

As previously discussed, AM is a digital and automated manufacturing technology whose adoption has implications in terms of employability since such automation reduces the need for employees. Indeed, contrary to most CM technologies, with AM, one operator can operate more than one AM machine at a time (Huang *et al.*, 2013). Tuck *et al.* (2007) reported an example of this reduced need for employees, showing that the hearing aid industry benefits from AM adoption for, among other things, reduced labor needs.

In conclusion, we can derive the following proposition:

***Proposition O5***: AM requires less workforce than CM techniques (an operator can operate more than one AM machine).

***Customization***

As reported by Huang *et al.* (2013, p.1191), an *“abundance of evidences were found to support the promises of additive manufacturing in … customized healthcare products to improve population health and quality of life”*. Indeed, contrary to CM technologies, AM, producing parts layer-by-layer, enables production flexibility and design freedom (Mueller *et al.*, 2020; Nazir *et al.*, 2021). This enables the production of customized parts that *“can possess complex features which are difficult to machine using conventional, subtractive methods”* (Emelogu *et al.*, 2019, p.2). This is highly attractive in medical applications where parts can be customized to the individual patient’s data with consequent benefits for the patient’s wellbeing (Muir and Haddud, 2018). Furthermore, topology optimization procedures are often employed to obtain superior functionality compared to CM counterparts (Emelogu *et al.*, 2019).

In conclusion, we can derive the following proposition:

***Proposition O6:*** AM enables a higher degree of customization than conventional manufacturing techniques, derived mainly from a higher design freedom (e.g. topology optimization procedures)

***Responsiveness (On-Demand Production)***

As reported by Huang *et al.* (2013, p.1191), an “*abundance of evidences were found to support the promises of additive manufacturing […] to increase […] responsiveness in demand fulfillment*”. This “*emphasizes the potential benefits of using AM for fabrication of biomedical implants*” (Chowdhury *et al.*, 2020, p.275) since medical supply chains, “*which require shorter lead times, high level of variety, flexibility, and customization, should rely on responsiveness*” (Emelogu *et al.*, 2019, p.39). The responsiveness of AM is explained by Franco *et al.* (2020, p.9): “*AM can increase the responsiveness of a business model, because a relatively fast turnaround time of the product to the consumers can be realized without any tooling. […] This access to […] on-demand manufacturing enhances the […] responsiveness to fast changing market demands*”.

In conclusion, we can derive the following proposition:

***Proposition O7:*** AM assures quick responses to new orders due to the on-demand production.

***Responsiveness (Geographical Convenience)***

AM can increase the responsiveness also through the possibility of producing parts close to the point of use. Indeed, following Franco *et al.*, (2020, p.9). “*AM allows goods to be produced […] at the point of use in space and time according to the exact required specifications. This access to local […] manufacturing improves flexibility and responsiveness to fast-changing market demand*”.

In conclusion, we can derive the following proposition:

***Proposition O8:*** AM assures quick responses to new orders due to the production close to the point of use.

***Waste Reduction***

As discussed above, AM technologies produce parts additively, adding raw materials layer-by-layer (Patil *et al.*, 2023). This leads to a raw material utilization that is much higher than CM technologies, which are instead subtractive technologies (Meyer *et al.* 2022c). A typical parameter used to express such efficiency is the buy-to-fly ratio[[1]](#footnote-1): AM technologies, allowing the production of near net shape products, lead to a buy-to-fly ratio that is close to 1:1, while CM technologies lead to a buy-to-fly ratio that typically ranges between 10:1 and 15–20:1, with peaks of 40:1 for complex components (Yusuf *et al.*, 2019).

In conclusion, we can derive the following proposition:

***Proposition O9***:AM assures a buy-to-fly ratio of almost 1:1, thus drastically reducing waste compared to CM techniques.

***MTO Production***

One of the advantages emerging from the fact that AM enables the production of parts without any tooling or set-ups is that AM “*facilitates on-demand production of personalized medical*”. Therefore, AM supports the design of parts “*under a Make-To-Order (MTO) strategy*” (Emelogu *et al.,* 2019, p.6), where inventory levels are reduced (Muir and Haddud, 2018).

In conclusion, we can derive the following proposition:

***Proposition O10***:AM enables the possibility to switch from make to stock (MTS) to make to order (MTO) and hence to lower inventory levels (and hence costs).

***Simpler Supply Chain***

As described before, Huang *et al.* (2013, p.1191) stated that an “*abundance of evidences were found to support the promises of additive manufacturing in […] simplified supply chain*”. Among the reasons leading to a simplified supply chain, the authors mentioned that “*the need for warehousing, transportation, and packaging can be reduced significantly*” due to the possibility of AM to produce on-demand and close to the point of use with a reduced number of actors involved in the supply chain (Choudhary *et al.*, 2021; Javaid *et al.*, 2021).

In conclusion, we can derive the following proposition:

***Proposition O11***:AM simplify the supply chain since it encompasses less actors in the supply chain.

***Part Consolidation***

As stated by Nazir *et al.* (2021, p.6), AM can have a *“remarkable impact on the production and distribution of products. The major advantage of AM lies in the consolidation of the components into a single product”*. Indeed, AM has superior design flexibility, with the *“ability to construct complex geometries” where “many previously separated parts can be consolidated into a single object”* (Huang *et al.*, 2013, p.1191). According to Son, Kim and Jeong (2021, p.7), part consolidation is *“the best approach to exploit the design freedom of AM”* and it represents *“the most significant advantages of AM”*.

In conclusion, we can derive the following proposition:

***Proposition O12***: AM enables to consolidate existing part assemblies made from many components into a single part.

***Shareability***

One of the key features of AM is the possibility of producing parts directly from 3D models (.STL files), which “*can be easily found and shared in makers hubs or even at social media*” (Longhitano *et al.,* 2021, p.20). As stated by Salmi *et al.* (2020, p.12), this ease of sharing design files represented “*one of the biggest reasons why 3D printing applications related to COVID-19 have been developed so rapidly*”. Indeed, “*during the pandemic, data sharing has rapidly increased to spread initiatives and solutions as an attempt to fight of the virus*” (Longhitano *et al.,* 2021, p.21).

In conclusion, we can derive the following proposition:

***Proposition O13***: AM allows to easily share products design as they only need to be shared via STL files to be ready to be printed.

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1. It is the ratio between the initial volume of raw material and the final volume of the finished product. [↑](#footnote-ref-1)