ADDITIVE MANUFACTURING, SUPPLY CHAINS AND ENVIRONMENTAL FOOTPRINT

By René Poirier, May 8, 2022[1]

Increasing the flexibility of supply chains and reducing the environmental footprint are two significant challenges that face our companies. Additive manufacturing (AM) offers part of the solution.

The Supply Chain Issue[i]

The war in Ukraine, COVID-19, a blocked Suez Canal, container shortages, forest fires in British Columbia and American tariffs on Canadian steel and aluminum have revealed the complexity and vulnerability of our supply chains to pandemics, armed conflicts, protectionist measures and logistical accidents, not to mention disasters caused by extreme weather events.

To mitigate these risks, experts recommend that companies diversify their supply sources, prioritize local suppliers (near-shoring) and those from allied countries (ally-shoring), make their supply chain management more "intelligent," and expand their production flexibility.[ii] In this context, additive manufacturing only increases its strategic value, as the World Economic Forum recently pointed out.[iii]

AM is an end-to-end manufacturing process that produces physical objects using 3D digital models. Printing is achieved by adding materials in successive layers (plastics, metals, ceramics, etc.), allowing for the rapid production of single, customized parts at stable unit costs, or High-Mix Low-Volume parts.[iv]

Thus, AM allows for greater freedom when designing parts based on a predictable performance, not machining and assembly constraints. The resulting products have fewer materials, fewer components and fewer assembly steps. This works to mitigate the impact of potential price increases, shortages and logistical problems. This level of optimization often improves the final product's performance while extending its life cycle.

Another significant advantage involves shorter lead times between design and production stages for parts and tooling, or when making tooling changes. Unlike die casting, a given part's creation and production could become a matter of days. The product's design, prototyping, refinement and reconfiguration could be achieved in a shorter time span without investing too much time and money in design iterations that would have taken months under conventional machining processes, or the production of moulds for the injection molding.[v] Efficiency is also improved with a single platform, thereby shortening the supply chain. And because AM uses digital models, design and data can therefore be shared and transmitted to decentralized 3D printers, or to printers located near users. This makes the company less vulnerable to delivery delays from distant suppliers.

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[1] The author is a member of the CQFA Steering Committee and a Senior Economist at Innovation, Science and Economic Development (ISED). He would like to acknowledge the *Carrefour québécois de la fabrication additive (CQFA)*, *PRIMA Québec* and Denis Akzam (P4BUS Systems) for their comments.

A great example of the design and production speeds involved occurred at the start of the pandemic. All over the world, companies, academics and professionals mobilized to design and produce medical equipment and supplies using AM. Over a short period of time, masks, visors and respirators were designed and delivered. In Quebec, several companies joined this global movement: Aon3D, AscensionX, Bodycad, CAE, Concepts 3DG, Dyze Design, eLab Extrusion, Fablab, FZ Engineering, Gf3D Prototype, Innovscan, Labo3D, MDA, Mekanisk, MI Integration, Nanogrande, OCX, Panthera Dental, Polycontrols, Safran, Spaceshift 3D, Tak Design, TechnoLaser, Voxel Factory, Zimmer Biomet, and many others.

AM provides on-demand production possibilities without the high minimum quantity requirements of conventional processes. This reduces the needs and costs associated with storing parts and end products. AM also represents a good option for end products that quickly grow obsolete within certain markets.

Finally, and despite a company's regular use of more conventional processes like die casting, AM's capabilities provide companies with greater production flexibility for contracts that require multiple copies of the same standardized product, or the production of large parts. Companies can also use a hybrid approach for certain parts, combining AM and computer numerical control (CNC) to reduce material, manufacturing and finishing costs. For example, parts can be produced with 3D printing then surface finished to the desired tolerance levels using a CNC machine. Alternatively, the part can be manufactured subtractively before adding inserts using 3D printing, a process that would otherwise require complex programming and hours of planning for a CNC machine. A good example would involve turbines, where the bulk of the part is made with a CNC machine, but the blades are made from AM and finished by CNC. Some machines, known as hybrids, combine both subtractive and additive processes with the same equipment.[vi]

The Environmental Footprint Issue[vii]

The United Nations defines sustainable development as one that meets the needs of the present without compromising the ability of future generations to respond to their own needs. Our use of nature against its own regeneration can be gauged through a variety of measurements, including environmental, ecological, climate and carbon footprints. The fewer natural resources used by a company, the less waste it creates, the smaller its environmental footprint and the more sustainable its development.[viii] Climate change and energy transition, as well as our carbon neutrality goal by 2050 make mandatory "greener" manufacturing processes and supply chains.

AM topologically optimizes printed products. The resulting products are lighter in weight and involve fewer parts, thus reducing the amount of material required. An additive approach to printing generates little or no waste beyond the occasional support structure, unlike CNC machines or die casting. Often, the resulting product will have fewer surfaces to rework and machine finish.

The unused surplus metal powders or resins that accumulate around the printed part can be reused more than once, then recycled in their entirety. Residual powders from medical parts with high-purity materials like tungsten can be recycled without the need for decontamination. This recovery saves material, energy and time.[ix]

The buy-to-fly ratio used in aerospace measures material savings. Printed parts provide an approximate ratio of 1.5:1 (the weight of materials used in relation to the weight of the end part), while those made by more conventional methods often provide ratios above 10:1. Fewer materials, fewer parts and lighter products also reduce the energy consumed and the CO_2 emitted while producing and transporting the parts, but also when maintaining spare parts inventories, which often deteriorate and lose value over time. Furthermore, manufacturing lightweight parts creates final products requiring less energy (typically hydrocarbons) throughout their useful life (as with transport equipment, for example).

AM can therefore extend the life of an end product when spare parts are no longer available, as surplus inventories are expensive to maintain when conventional mass production ends. Repairing and replacing parts requires nothing more than printing designs using an inventory of 3D digital files – crucial steps in a circular economy.

The energy consumed through additive and subtractive processes is more difficult to compare, since it varies greatly from one stage to another throughout the product's value chain and life cycle. When compared to die casting, the prefabrication and manufacturing stages are more energy intensive for powder atomization (plasma, gas and water), as well as for 3D printing. And 3D printing often requires more time; several hours as opposed to several seconds or minutes per part for castingg. Other factors are involved as well, like the energy savings that come with AM, which consumes only the material required and generates less waste to manage, the possibility or not of reducing production volumes where smaller batches favour AM, and the energy consumed in a die casting process to manufacture molds.[x]

Roland Berger recently demonstrated that the production of 3D printed parts for gas turbines, autoclaves and aerospace applications requires more energy than conventional processes, but the energy savings that result from the product's end use during its life cycle more than offset the upstream energy required to manufacture the AM materials and print the parts.[xi] Researchers at Purdue University reached similar conclusions for turbine trough repairs.[xii]

American researchers at the Universities of Idaho and North Dakota have shown that the additive manufacturing of a stainless steel pump using laser metal deposition (LMD) is less harmful than casting for its global warming potential (GWP), acidification (AP), freshwater ecotoxicity (FAETP), human toxicity (HTP), and stratospheric ozone depletion (ODP). Researchers from the Universities of Alabama and Shandong reached similar conclusions for all metallic AM processes. They also highlighted the importance of optimizing the use of platens, chambers and enclosures.[xiii] Environmental footprints are further reduced when clean energy like hydroelectricity is used to manufacture and 3D print the materials, as practised in Quebec.[xiv]

AM uses gases at various stages, from material manufacturing to post-manufacturing, from powder storage to handling and transportation. These gases include nitrogen, argon and helium, along with hydrogen when water atomization is used. The energy cost when producing these inputs must be considered. Various safety measures govern these operations since the gases and particles emitted can be toxic to the skin, eyes and respiratory system. These risks are minimized through masks, suits and respirators when manufacturing powders, and through well air-conditioned premises and properly sealed 3D printers. Standards govern product quality and safe usage, like the ASTM/IS 52907 standard for powder inerting.[xv]

The *Carrefour québécois de la fabrication additive (CQFA)*

Recent years have seen a reduction in the risks and costs associated with AM-related innovation, exploration, adoption and control.

AM technologies are constantly evolving. The parts' manufacturing speed continues to improve, along with their quality and size. New and emerging materials suitable for manufacturing processes have already been characterized. More and more companies are using AM to customize products, while the number of industrial and mass production applications continues to grow. Major OEMs, including GE Aviation, Raytheon, Siemens Energy, Lockheed Martin and Honeywell are outsourcing more of their AM parts and products as they develop and integrate their SME supplier networks within their supply chains.[xvi]

3D printers can now be rented with payment plans based on usage or the number of parts produced, transforming what was once a significant capital expenditure (CAPEX) into an operating expense (OPEX). [xvii]

The governments of both Quebec and Canada offer a number of assistance programs to help acquire equipment, modernize facilities and upgrade workforce skills. These include the Digital Transformation Offensive (OTN), *Impulsion-Compétences*, the *programme de formations de courte durée* (COUD), the Canada Digital Adoption Program (CDAP), and the Upskilling for Industry Initiative (UII) program, among others.

Many diploma-based and qualification courses have appeared to facilitate AM learning in Quebec. And since June 1, 2022, the Carrefour québécois de la fabrication additive (CQFA) has been hard at work to promote the expertise of Quebec's various AM stakeholders while sharing knowledge and experience within the ecosystem, encouraging collaborations and stimulating business opportunities (www.cqfa.quebec).

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