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Arms and the Man: Strategic Trade Control Challenges of 3D Printing

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Arms and the Man: Strategic Trade Control Challenges of 3D Printing

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Abstract

Three-dimensional printing is on the verge of introducing security agencies globally to a whole new set of mind-boggling problems. These machines are quickly overcoming hurdles in the path of crafting nuclear centrifuge components. Further, with the tremendous reach of the Internet worldwide, virtual blueprints for small arms, drone components and accessories, narcotic drugs and psychoactive substances, as well as dual-use items can be printed out by individuals or organizations that have access to good 3D printers. Modern technological innovation is currently outpacing the legislative response from legal institutions and security systems, both of which must be revamped in order to tackle impending threats on the horizon. Though 3D printing is one of a slew of these new technologies that require scrutiny (others include artificial intelligence and quantum or nanotechnologies), updating the Multilateral Export Control Regimes well in time to mitigate novel trade control challenges posed by 3D printing is the need of the hour. This article details the imminent security threats in this world of manufacturing evolution and revolution and proposes various methods to address and counteract those threats.

I. Introduction

Three-dimensional printers—the magical devices capable of printing prosthetics, violins, and even aircraft parts—have the potential, as US President Barack Obama observed, "to revolutionize the way we make almost everything." The flipside to all their good uses, however, is the fact that these same machines can be used to create weapons and other harmful substances and equipment that can be used with pernicious intent. While not easily accessible to most people even today, 3D printing (its technical term is additive manufacturing) is in fact a reality that is becoming more sophisticated at every instant. This paper tries to answer the question of whether increased availability of this technology amounts to an increased slew of security challenges. The paper also asks the question: does the possibility of weapons proliferation posed by 3D printing—and the concomitant security challenges—outweigh the usefulness of the technology? Probably not yet. Nonetheless, despite the multifaceted advantages 3D printing brings to scientific advancement, I argue that security threats resulting from it are multiplying exponentially, and that 3D printing is detrimental to international security and could present a veritable nightmare for security agencies.

Three-dimensional printing is already being used in the nuclear industry, for instance, at the Sellafield reactor in the UK, where 3D scanning and printing technologies have been used in the manufacture of metal lids for low-level waste containers to move waste around the site **[*1*]**. In India, the Department of Atomic Energy is headed by the Prime Minister, and the Raja Ramanna Centre for Advanced Technology located at Indore, functioning under this department, has crafted nuclear components for the reprocessing plant and the Prototype Fast Breeder Reactor at the Indira Gandhi Centre for Atomic Research, Kalpakkam, India **[*2*]**. As the technology matures, the relative simplicity and economy of 3D printing technology could make it the industry standard for manufacturing. This seems to be the appropriate time for world governments to cooperate on how best to regulate the hazardous aspects of 3D printing and contemplate the future of strategic trade controls with respect to this technology before its use becomes more widespread. Regulatory measures require careful chalking out well before the problem becomes ubiquitous. Prevention is better than cure.

This paper thus focuses on an important yet relatively little-researched topic—namely the importance of developing adequate trade control laws and enforcement for 3D printing—and consequently examines the challenges posed by 3D printing to nuclear and global security. It also recommends modifications to the current international export control regime that would aim to mitigate associated security threats. The first section of the article introduces the topic and highlights the historical development of 3D printing, including its growth in various countries; it also provides information on the manufacturers, their profitability, their location, and their focus on other products. A literature review follows in the second section, discussing other articles in academic journals related to 3D printing and how this article differs from those articles. The next section focuses on different challenges and benefits of 3D printing and its various applications, while the fourth section discusses examples of "new" products in the past which introduced similar challenges to those introduced by 3D printing, and how those challenges were handled in the past. The final section suggests strategies and recommends ways to tackle these challenges posed by 3D printing. While this paper faithfully catalogs the various security challenges of 3D printing so far conceived, it also builds upon previous literature in two ways. First, it traces which nations are the primary manufacturers of 3D printers and thus provides a picture of the global hubs of 3D printing technology. Second, it focuses on various proliferation pathways previously not explored in detail—the most sensitive ones relating to nuclear technology and missile component manufacturing (as most research looks at gun control only)—to try to determine whether the extant legal and regulatory frameworks for countering those pathways are sufficiently robust, and then offers policy recommendations based on that analysis.

II. What is 3D Printing?

In layman's language, additive manufacturing, or 3D printing, is a process of making three-dimensional solid objects from a digital file. The creation of a 3D printed object is achieved using additive processes. An object is created by laying down successive layers of material until the entire object is created. It all starts with making a virtual design of the object one wishes to create. This virtual design is made in a Computer Aided Design (CAD) or a Stereolithography (STL —a proprietary format of the company 3D Systems) file using a 3D modeling program for the creation of a totally new object, or with the use of a 3D scanner to copy an existing object. To prepare a digital file for printing, the 3D modeling software "slices" the final model into hundreds or thousands of horizontal layers. The object can be created layer by layer. The 3D printer reads every slice (or 2D image) and creates the object, blending each layer with hardly any visible sign of the layers, resulting in the 3D object. Initially, 3D printers could print using only a single material at a time. Today the technology has changed dramatically to allow multiple materials to be used in printing at the same time, and new technology advancements could soon allow objects to be used immediately after printing **[*3*]**.

Today, there exist two broad categories of 3D printing in terms of the scale of the final product:

(1) *Personal Printing* – This is primarily for hobbyists and enthusiasts. It started growing in 2011. Rapid developments within this new market make printers cheaper and cheaper, with prices typically in the range of $250 – $2,500. This makes 3D printers affordable to a greater number of people, even those in the middle-class income bracket. It would be a cause for concern if blueprints of sensitive/high tech items were to land in wrong hands.
(2) *Industrial Printing* – Large 3D printers have been developed for industrial, educational, and demonstrative uses. A type of large printer is the Big Area Additive Manufacturing (BAAM) type. The current goal is to develop printers that can produce objects up to 100 feet long in high speed (Lockheed Martin, Cincinnati Inc.). There is cause for concern here in that mushrooming companies with no internal compliance programs may export dual-use products from their industrial 3D printers.

Current filament types used in 3D printing are particular kinds of polymers—Acrylonitrile butadiene styrene (ABS) or Polylactic acid (PLA). Certain printers, like the Mark One, can also use carbon fiber, fiberglass and even Kevlar. However, there is an increasing proclivity towards 3D printers which can also process other, more complex materials such as ceramics, biological tissue, metals, powders, etc. There are a few types of metal printing technologies such as stereolithography, Fused Deposition Modeling (FDM), inkjet bioprinting **[*4*]**, Selective Laser Sintering (SLS), Selective Laser Melting (SLM) and Direct Metal Laser Sintering **[*5*]**, which can 3D print a wide array of metals, including stainless steel, titanium, Inconel (a nickel-chromium alloy), maraging steel (a class of low-carbon, high-nickel stainless steel that has been precipitation-hardened or 'aged'). Some 3D printers can even process human tissue. There is already a plethora of sensitive areas that are associated with 3D printing today, such as aerospace, automotive, bioengineering and biomedical devices, chemical engineering, electrical-mechanical systems, the fashion industry, industrial manufacturing, internet, machine technology, materials, nanotechnology, pharmaceuticals, robotics, semiconductors, software, textiles, and wearable technology **[*6*]**. Further, NASA has gone to the extent of funding an experimental machine for 3D printing pizza **[*7*]**.

The major difference between 3D printing and traditional manufacturing is that while in traditional manufacturing subtractive processes are typically used, such as cutting, drilling, milling or grinding, 3D printing is an additive process that fuses materials, layer on layer, using a combination of heat, chemicals, light, electron beams, or adhesives **[*6*]**.

According to the website *investingnews.com*, the 3D printing industry is slated to breach the $30 billion mark by 2022 **[*8*]**. Though it is still a niche area with few companies of the world engaged in it, some large multinationals, such as Hewlett-Packard, are showing interest in diversifying their businesses with 3D printing. The largest 3D printing companies—as well as the largest number of 3D printing companies—such as 3D Systems and Stratasys, are based in the USA, while many others operate in Europe, and still others in Canada, China, Japan and the UAE. Chinese authorities in Chongqing have taken the step of having all 3D printing companies register their businesses with the local police in order to monitor any suspicious output **[*9*]**.

III. Literature Review

A large corpus of research on the potential hazards of 3D printing technology has been directed at the manufacture of guns, rifles, and other small arms. For instance, S. Magnuson, in his brief write-up on 3D printing, observes that prices of 3D printers are drastically decreasing to reach to the point that hobbyists and enthusiasts are beginning to be able to afford them. That fact, he argues, coupled with companies like Shapeways Manufacturing—which custom-makes 3D printed products for online customers, often without knowing what they are manufacturing or how a customer might use that product—raises security concerns. Three-dimensional printing could change the way products are distributed the way MP3s changed how music was consumed **[*10*]**. Others in the early days of 3D printed gun manufacture felt there was no significant new threat posed by this technology. Gerald Walther in 2013 observed that 3D printed guns did not threaten to cause significant harm because they were in the nascent stages of development and not greatly effective **[*11*]**.

The threat, however, is from more than just firearms. As the website *The Conversation* has noted, countries (or non-state actors, I would add) "seeking to develop nuclear weapons could use 3D printing to evade international safeguards against nuclear proliferation. Traditional nuclear weapon control efforts include watching international markets for sales of components needed for manufacturing a nuclear device. Additional measures place restrictions on the types of technology nuclear-capable states can export. 3D printing could avoid these efforts by letting countries make the equipment themselves, instead of buying it abroad." Scholar Grant Christopher recommends that governments as well as the Nuclear Suppliers Group (NSG) introduce export controls for 3D printers based on certain parameters **[*12*]**. Christopher further observes that technical experts need to work hand in hand with policymakers to address the issue of regulating 3D printing technology at the earliest stage before a Pandora's box opens **[*12*]**. Matthew Kroenig, of Georgetown University, and Tristan Volpe, of the Carnegie Endowment for International Peace, asserted in a jointly authored article that there is still time for the United States to spearhead an international effort to contain the 3D printing genie in the bottle, particularly as its proliferation potential has not yet fully materialized **[*13*]**.

Some, but by no means exhaustive, research has also been done on 3D printing of nuclear weapons components, the state of the current export control frameworks meant to keep up nonproliferation, and how they measure up against this new technology. Among the highly educative recent works in this category is one by the James Martin Center for Nonproliferation Studies (CNS) that has analyzed a set of export-controlled items to understand the degree to which 3D printing might be used to produce dual-use goods useful for the development of WMDs. They analyze this issue at three different levels: the "item" level, the "legal user" level, and the "illicit user" level. At the item level, this study did not find any evidence that 3D printing is being used to support WMD development actively. At the legal user level, it finds that 3D printing technology is proliferating. Finally, the illicit user level results are similar to the item level results. However, this technology, it observes, is within the reach of the Islamic State (IS) or North Korea, should they wish to actively pursue developing weapons using 3D printing **[*14*]**.

Numerous international laws have been propounded across countries, usually in line with the Multilateral Export Control Regimes (MECRs), to reduce, if not stop, proliferation of weapons technologies, especially from getting into the hands of terrorist organization. However, the efficacy of these laws has yet to be fully proven as even today there are numerous instances of stabbings, shootings, cyberattacks and statements of intent to use nuclear weapons on the part of terrorist groups. One example of the latter was Osama bin Laden's statement termed "The Nuclear Bomb of Islam," which declared that, "It is the duty of Muslims to prepare as much force as possible to terrorize the enemies of God" **[*15*]**.

While not reinventing the wheel, it is still appropriate to point out that so long as these technologies do exist, there will always remain a certain level of threat and discomfort. The same is the case with 3D printing. What is critical to know about this technology is that it will remain a double-edged sword as long as it exists. The times one lives in and the technology prevalent in those times are deciding factors in what issues will take center stage in that period. The early 21st Century is the time of, among other things, 3D printing. The technology has steadily advanced to the point that several guns and critical components for semi-automatic rifles have been manufactured, and the US army is also developing a new, 3D printed grenade launcher. With that in mind, the naysayers claiming that 3D printing does not pose any threat should reconsider their arguments. This paper argues that 3D printing indeed presents security challenges—and it proposes solutions.

IV. Theory: The Black and White of 3D Printing

3D printing, as originally intended, is indeed a game-changing technology that has the potential to create new opportunities and change human lifestyle for the better in various ways. It is often referred to as something that will herald the next industrial revolution. Dentists can make dental crowns and on-site bridges in about an hour, cranial bones can be fixed without waiting for metal plates, and custom-made prosthetics can be created swiftly and economically **[*16*]**. Three-dimensional printed medical implants are being used already for veterinary purposes **[*17*]**. Cost-effective fabrications of medical components, car parts, fuel cells, costumes, aviation parts (such as for GE's commercial jet engines), rocket engines, and lesser dependence on trade with other countries attributed to production self-sufficiency are slated to be the primary advancements.

Other key benefits of 3D printing include customizing products, reducing production time, localizing production and reducing logistical woes, such as eliminating the need to transport component parts required for manufacture when those different parts could be manufactured in-house with 3D printing. The US Navy's Chief of Naval Operations' Rapid Innovation Cell (CRIC) started the 'Print the Fleet' program in 2013, and as of 2014, there were 60 additive manufacturing-related projects in the US Navy. The head of the 3D printing program, Jim Lambeth, stated, "Really what the project aims to do is develop procedures and policies for printing parts, how to qualify the parts, deliver the parts … and how to use these printers" **[*18*]**. More recently, in 2016, a California-based company called Make in Space provided the second 3D printer to the International Space Station so that a wrench could be manufactured in space without having to wait for supplies from earth. Now other tools can be created by the astronauts in space using the printer as well **[*19*]**. In another instance, the US Marine Corps Commandant declared that his teams would not have to carry their tents anymore and instead could simply print them when they arrived at their destinations **[*20*]**. Further, the Contour Crafting technology developed at the University of Southern California is being used in conjunction with NASA to print 2,000 sq. ft. homes in less than a day's time. If successful, this could be another "giant leap for mankind" with bases far more easily constructed with local moon materials as opposed to shipping the material from earth, costs of which are exorbitant: a single pound of raw material from earth to the moon costs roughly $100,000 with current technology **[*21*]**.

While the possibilities of using 3D printers for benevolent and innocuous ends are limitless, the light at the end of the tunnel could also mean a train is coming. This danger is exacerbated by the fact that traditional export controls deal with tangible technology, while a major part of 3D printing technology deals with Intangible Technology Transfer (ITT) of digital file blueprints that would then be used to produce an object. Thus, according to a Stockholm International Peace Research Institute (SIPRI) study, "controls on technology mean that transfers of the build files used to produce 3D printed objects could require a license if the items they describe are themselves subject to control and they provide a knowledge transfer beyond the pure geometry of the object, for example, the technology for specific processes and finishing procedures that make the item more heat-resistant." The difficulty therein is that this law is interpreted and implemented differently in different states **[*22*]**. Further, the printers themselves and the software they use to produce objects are not export controlled yet **[*22*]**. Controls need to be implemented and perhaps could be applied at the printer, the material, or at the file level—or on all those levels. Thus, the many legal and regulatory frameworks governing dual-use technologies can only minimally, and inadequately, ameliorate the proliferation and security challenges posed by 3D printing.

V. Hypothesis

Instances of 3D printing have already generated threats to security, and in some cases have resulted in security breaches. Three-dimensional printing could make extant export control laws and border security methods obsolete as the digital domain becomes embodied in physical objects. Further, this new technology could have implications for the future of nuclear security. This leads me to the hypothesis I propose to test:

H_A: The proliferation of 3D printing technology will lead to heightened security and export control challenges globally.

My independent variable (X) is thus proliferation of 3D printing technology and my dependent variable (Y) is heightened security and export control challenges globally. The illustrations provided in the theory section testify to evidence of a causal connection between the variables X and Y in the real world.

As the US Department of Homeland Security has rightly observed, “Significant advances in 3D printing capabilities, availability of free digital 3D printable files for firearms components, and difficulty regulating file sharing may present public safety risks from unqualified gun seekers who obtain or manufacture 3D printed guns," and "proposed legislation to ban 3D printing of weapons may deter but cannot completely prevent their production. Even if the practice is prohibited by new legislation, online distribution of these 3D printable files will be as difficult to control as any other illegally traded music, movie or software files.” Here, the Department refers to only one potential concern with 3D printing. However, the complexity of the issue is far greater. Several other risks to strategic trade controls posed by 3D printing can be identified, one among them being printed handguns and rifles. However, the greater threat, though harder to achieve, is the possibility of crafting nuclear centrifuge parts. It is a pertinent worry as long as a well-funded terrorist organization such as the Islamic State (IS) exist.

VI. Maraging Steel in Nuclear Reactor Centrifuge

Maraging steel, mentioned earlier, is a key component used in the nuclear fuel cycle as it has the relevant characteristics required for centrifuges used to enrich uranium—in particular, maraging steel can be used to create the rotor, baffles and endcaps. Concerning high-strength materials, only high-strength aluminum, maraging steel, and carbon fiber are free from any strategic trade control laws for possible use in centrifuges. Though 3D printing maraging steel is not as simple as ‘click and print’ from the CAD file—because the required dimensions must be replicated with close to one hundred percent density to keep the strength of the material intact—hurdles in the path of producing 3D printed maraging steel with properties comparable to manufactured maraging steel are gradually being overcome. Three-dimensional printers currently capable of producing maraging steel are limited to a handful only, such as the EOS M series **[*5*]**, the Matsuura Lumex Avance-25 **[*23*]**, Renishaw AM250 **[*24*]**, SLM 280 or SLM 500 **[*25*]** and Concept Laser machines **[*26*]**. As the mists clear over the processes of 3D printing and existing procedures are parametrically refined, it becomes gradually more conceivable that the current generation of 3D printers could be used to manufacture key components of some of the sensitive and controlled technologies in the nuclear fuel cycle **[*12*]**. The current crop of carbon fiber, aluminum, or plastics resistant to the corrosive UF6 chemical at present may not be able to create the required centrifuge—perhaps because of strict geometric quality requirements (for 3D printed carbon fiber), higher tensile strength (for 3D printed aluminum), or a lack of effective melting upon heating (for 3D printed, fully-fluorinated plastics), and a metal printer would cost around $7,500,000 and take 1–2 days to manufacture the 3D printed centrifuge **[*12*]**.

Nonetheless, developments of the technology in this direction should be monitored because of the motivation, and even partial capability, of certain terrorist groups to acquire nuclear weapons. The recent James Martin Center for Nonproliferation Studies (CNS) report on 3D printing succinctly sums up why: “Although we lack evidence about whether AM has hitherto been used by any non-state actor (or even by a state) in WMD production, the aerospace industry is using the technology to produce precision components of high significance and utility. This underlines a genuine concern that the technology can be used for construction of components related to critical weapons or even a nuclear device… since AM requires only the blueprint and 3D printer, it reduces the technical threshold required for manufacturing the necessary material and even constructing the weapons. It subsequently affects strategic trade because it reduces the dependence on conventional illicit trade networks substantially. In addition, 3D printing requires only a small space instead of a big manufacturing facility. The dual-use nature of 3D printing exempts it from many export control limitations and makes the technology easily accessible to anyone, including terrorist groups… this problem is compounded by the fact that the technology is already present in Makerspaces that are within the operational spheres of potential WMD terrorists, creating easy access and potential for misuse" **[*14*]**.

This implies that a terrorist organization such as the Islamic State could use their considerable financial resources and smuggling and black-market networks to potentially gain access to this technology available in countries in the Middle East and North Africa (MENA) region such as Morocco, Egypt or even closer to Pakistan in South Asia. IS apparently has the capabilities to build Improvised Explosive Devices (IEDs) and weaponized drones on a quasi-industrial scale **[*27*]**. "More surprising is the fact that it has cobbled together a supply-chain network involving some fifty companies spanning over twenty countries. There is documented evidence that within this network, Turkey has been the chokepoint of this illicit procurement supply chain, which raises the possibility that the IS possesses the ability to illicitly procure AM technology and related material through Turkey" **[*14*]**.

VII. Microchips and Guided Missiles

Microchips with applications in sensitive systems and other sophisticated technology could similarly end up in unwanted hands. The major US defense contractor Raytheon has recently manufactured most parts of a guided missile through 3D printing as part of a $523 million contract from the US Department of Defense **[*28*]**. According to Raytheon, "Engineers are exploring the use of 3-D printing to lay down conductive materials for electrical circuits, create housings for the company's revolutionary gallium nitride transmitters, and fabricate fins for guided artillery shells. … [R]ocket engines, fins, parts for the guidance and control systems, and more" have already been manufactured with this technology **[*28*]**. The outstanding benefits of 3D printing then are the far shorter production cycles, cost effectiveness, easier supply chain with fewer pieces—all this versus traditional manufacturing methods. The costs in manufacturing these components are cut down drastically because unlike regular manufacture, which is subtractive in nature (removing unwanted sections of expensive parts), additive manufacturing results only in addition of the required parts, leading to negligible waste or to no waste at all.

While there is still time, and while manufacturers are still grappling with the production of the remaining parts (metallic strongbacks, plastic connectors, semiconductors for processors, electronic circuits, microwave components, and propulsion systems) and in making the connections between these parts, it may help the Missile Technology Control Regime (MTCR), one of the MECRs, if more detailed analysis could be done in this field by scrutinizing which components of ballistic missiles can be crafted in the present moment, or in the near future, using existing 3D printing, with the aim of bringing those components under binding export control laws.

VIII. 3D Printed Small Arms and Light Weapons (SALW)

Three-dimensional printed small arms such as handguns and crossbows may well be a source of major hazard, as blueprint files are already freely available online. Piratebay.org hosted downloadable "The Liberator" diagrams long after Cody Wilson was asked to take them off his Defense Distributed website. Many individuals have threatened harm to the United States upon acquiring gun blueprints **[*29*]**. This could be a hoax, but, if true, could lead to tragic consequences if left unattended. Downloads of the plans from the UK, Germany, Spain, and Brazil were considerable. Further, plastic guns are invisible to metal detectors and X-Ray machines, which could prove to be a challenge for Customs worldwide unless personnel are sufficiently trained and appropriately equipped in advance.

In countries like Japan, the United Kingdom and Australia, among others, where there are strict controls on guns, people may choose to print the weapons as a way to circumvent existing controls. Guns would not have to be physically imported; weapons without serial numbers do not require background checks to acquire and can be manufactured at home if a decent 3D printer is available. Considering the fact that the availability of 3D printing is growing exponentially, and that the human brain has limitless potential, it is reasonably to ask how long it might take for mankind to reach the stage where we will be printing rocket launchers or even more devastating weapons. In the case of recent terrorist attacks, whether in Mumbai (2008) or Paris (2015), guns and other munitions may have been bought, legally or illegally. What happens if the same terror groups acquire the knowhow to 3D print the required weapons based on blueprints available online, and there are no existing serial numbers associated with the weapons in order to trace them? Border checks on arms smuggling would become increasingly ineffective. Applying for gun licenses would become meaningless. The danger can spread swiftly. In June 2015 in Hong Kong a group of terrorists with a 3D printer, bombs and guns was apprehended. Numerous handguns, rifles and rifle parts have already been produced around the world, with the great majority coming from the United States.

Varieties of 3D printed SALW abound. Examples are provided below to trace the progression of weapons of this class, from the first one made to one of the latest to be created. They are as follows:

- The Liberator (USA) – Defense Distributed (2013)
- Rapid Additively Manufactured Ballistics Ordnance (RAMBO) – US Army (2017). Grenade launcher – 48 out of 50 components of the weapon itself were 3D printed. Three of four ammunition parts (grenades) were also 3D printed **[*30*]**.

From the last example, one notices that the US Army has already almost entirely manufactured a grenade launcher using 3D printing. If this trend continues, it will not take long for other armies to catch up, and some of these armies could have links to non-state actors or could support state-sponsored terrorism.

IX. Drone Accessories

Drone accessories, like 3D printed cameras, landing gears, propellers, etc. are available online and can be shipped to most countries, increasing risks of malevolent drone usage. The internet is full of websites referring to 'do-it-yourself' drone kits with which one could build inexpensive lightweight drones. Drone accessories, like camera holders, can be printed out too. For the motors, batteries at current technology levels still need to be attached separately and cannot be 3D printed. However, a whole gamut of accessory options is offered, ranging from customizable 3D printed drones with autopilot, to the more advanced modular 3D printable drones designed to fly in flocks and communicate with each other, developed by the Institute for Dynamic Systems and Control based out of Switzerland **[*31*]**. In Britain, terrorists may try to use drones to commit atrocities or use 3D printers to build bombs, as Mark Rowley, Metropolitan Police Assistant Commissioner and the country's senior most counter terrorism officer, observed at the Counter Terrorism Expo Conference in London **[*31*]**.

X. Nanotechnology

Three-dimensional printers using micro- and nanotechnology can result in micro-miniaturized 3D printed products. Already, 3D printing is at a sufficiently advanced level to be able to print lithium-ion micro-batteries of dimensions similar to those of a grain of sand (average diameter 0.0625mm-2mm). These batteries were printed by a team of scientists based at Harvard University and the University of Illinois at

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Urbana-Champaign with precisely interlaced stacks of tiny battery electrodes, each of them thinner than a strand of human hair (0.017-0.018mm diameter). A team from Urbana-Champaign had already worked on a polymer ink as far back as in 2007, which emulates the way spiders spin silk, where protein solutions solidify upon exiting the animal's body to become silk. The researchers designed this new ink consisting of two oppositely charged polymers. A syringe loaded with these liquid polymers squirts out the mixture, which, when passed through a mixture of alcohol and water, coagulates into filaments **[*32*]**. Similarly, a 285-nanometer long racecar model has been printed at the Vienna University of Technology in four minutes. The 3D printed car resembled the CAD file at a precision of plus or minus one nanometer, using a method known as two-photon lithography **[*33*]**. Of possible concern in the future is the manufacture of nanobots, once methods to control nanojets (streams of 3D printing polymers emanating from a printer at the nanoscale) are sophisticated enough to realize rapid 3D printing of complicated shapes. Research into the improvement of nanofabrication technology has been ongoing at the Seoul National University, with initial findings published in 2014. Nanobots could be used for military surveillance purposes if fitted with miniature cameras, or they could be used to disrupt an enemy's communications systems while being extremely difficult to trace. Micro-fish the width of human hair—developed at the University of San Diego, California with 3D printing—were designed to deliver drugs at specific locations within the human body **[*34*]** but could possibly be used for more pernicious purposes like assassinations by delivering toxic material in the same manner. Customs would be challenged because many handheld or doorframe metal detectors would not have sensitivities necessary for tracing objects of nano-dimensions. In a fast-paced airport or cargo environment, where clearing passengers and goods swiftly is of utmost importance, detecting objects of such minuscule proportions is bound to be a major enforcement challenge.

While we are still grappling with the strategic trade control ramifications of 3D printing, it may be apt to point out at this juncture that the Northwestern University's (Chicago) International Institute of Nanotechnology has received a grant of $8.5 million from the US Department of Defense to develop the 4D printer, meant to function at the nanoscale, which would advance materials sciences, chemistry and defense-related fields with what is being called 'smart' materials that are sensitive to other materials, signals and the environment. "The 4D printed objects would be able to transform and morph to fulfill other functions, due to encoded information on nanomaterials. The printers themselves work through a team of pens producing the materials which can act on numerous levels as it is imbued with electronic and chemical elements" **[*35*]**. Technology is moving so fast that updating the laws accordingly becomes a Herculean task.

XI. Cybersecurity

Cyberattacks on 3D printers have become a new worry for policymakers because the CAD files used in printing are vulnerable to such attacks. "The technology comes at a price, and the price is the possibility of stealing those files or intellectual property or sabotage," observed New York University Professor Nikhil Gupta. According to Gupta, hackers could steal sensitive CAD files for weaponry or other parts, or enemies could introduce a bug through a cyberattack into a sensitive file or the printer's firmware, which would cause a high-end product to fail. The FBI also raised concerns about hacked 3D printers, designed to manufacture bombs, exploding at unexpected times due to manufacturing defects introduced by external parties through cyberattacks on the 3D printing blueprints **[*36*]**. Further, according to a RAND Corporation paper under their *Security 2040* series, "Attacks will begin to have real-world consequences beyond the digital space and will increasingly blur the lines between kinetic and non-kinetic threats" **[*3*]**.

XII. DNA

Finally, companies have recently begun printing and selling DNA. In this case, 'printing' means making a high number of copies in a minimal amount of time. While this practice could lead to medical advancements or to better genetically engineered crops, it may also create significant problems in the Customs and cross-border trade domain. The CEO of a San Francisco-based enterprise, Cambrian Genomics, speaks openly about the possibility that everybody may soon be able to create novel creatures. He goes on to state that some viruses may be created, such as Ebola or Smallpox, with around 18,000 base pairs of DNA, which could kill millions of people at a single stroke **[*37*]**. Similarly, exotic life forms may be created. Cross-border wildlife trafficking may, as a result, assume completely different characteristics, an idea that seems straight out of 'Jurassic Park.' The concept of such incredible power through 3D printing, though not a worry of the immediate future, may be a point worthy of consideration if it is in the hands of potential terrorists with no global boundaries whatsoever. Though it must be accepted in today's times that 3D printing technology has not reached such epic proportions as to be able to genetically engineer whole organisms, it is entirely feasible that after a decade or two at its present, galloping pace, this unimaginable feat may become a possibility. The sky seems to be the limit.

XIII. Recommendations – Navigating the Gray Areas

- Governments must swiftly realize the need to anticipate 3D printing-related problems and customize laws to counter their unchecked spread in advance. Customs authorities, licensing agencies and other enforcement departments need to be sensitized to this technology. Much of the problem for enforcement agencies here boils down to the basic issue of the use of the all-pervading Internet as a tool for spreading blueprints. It may be prudent to lay down strategic trade control regulations for blueprints and virtual diagrams, CAD files of arms, weapons parts and dual-use technology parts (basically the 'knowhow') because current regulations fail to even meaningfully govern the 3D printing of guns, etc., as there is a lack of any effective means of controlling and standardizing the distribution of CAD files online. Designs specifically for items of concern can be controlled. Precedence exists for this. The Multilateral Export Control Regimes (MECRs) typically control "technology." For guns, military equipment and controlled dual-use technology, controls on intangible technology already exist. Perhaps controlling the operating systems of 3D printers may prove to be useful. However, an enabling technology such as 3D printing may get partially stifled in the process. The pros and cons need to be weighed carefully here.
- The MECRs can control the transfer of 3D printers. Precedence can be seen in the case of Computer-Numerically Controlled (CNC) machines, presently controlled by the Nuclear Suppliers Group and the Wassenaar Arrangement, as this type of machinery is capable of manufacturing highly-specialized components for use in military and nuclear applications. Arms, technology, and software associated with arms production fall under the purview of the Wassenaar Arrangement. Specialist 3D printers should be controlled if the equipment possesses advanced destructive capabilities **[*38*]**. Even at the domestic retail level, background checks of persons can be instituted before any printers are sold.
- Governments should institute controls on the supply of 3D printing-related material globally. This is probably a tough ask considering that with most dual-use technology or with materials that can be used in manufacturing different products, banning plastics and metals which can be used for various purposes can cause difficulty to other industries. It is also impossible to keep track of the identities of every importer globally procuring these materials.
- Tracking and disrupting the functioning of those who are sharing and downloading 'sensitive' 3D files online. Searching for common files, platforms and mapping those who have viewed and shared such files is perhaps a logical step to put an end to what is a very handy resource for terrorists and criminals.
- To thwart cyberattacks, following an example of the Danish corporation Create It REAL, heightened encryption processes can be used to keep CAD files from being altered remotely. It should be ensured that the decryption is possible at the 3D printer itself, to maintain the sanctity of the file during its journey through cyberspace **[*36*]**. Further, it may be worthwhile to consider,

"creating local interconnected networks, rather than connecting a 3-D printer to the entire internet and requiring a security key before an item can be printed" **[*36*]**.

XIV. Conclusion

As long as human beings have existed, there have been emerging technologies and discoveries. Novel technologies were developed, however, at a far slower pace in the years preceding 1800 CE or so, following which there began an exponential increase in new products and services. However, even when something as elementary as fire was first harnessed by man, it would surely have been a seemingly miraculous asset and would have opened the doors to many possibilities to make the quality of human life better—to stay warm, produce light in the darkness, ward off beasts in the wild, and so on. While running the risk of sounding Marxian, one could perhaps rightfully observe that once humankind developed a sense of material possession, that same fire—giver of light, warmth and a sense of security—became a tool in the hands of some to burn their fellow human beings, either to defend their own, or worse, to loot others' possessions. Similarly, over time, many new technologies have caused harm as well as good. Whether one considers basic tools like knives or more sophisticated armaments like guns, rocket technology (to carry humans to space or to bomb other nations), nuclear technology, drone technology (for taking innocuous pictures or for military reconnaissance and warfare), or even the internet and associated computer software, they can all pose different risks depending on whom is in control of this technology and power. They are all fit to be 'dual-use' items, even if in some instances in a more unconventional sense. Now, 3D printing looks slated to be the next big thing: it is one such technology impacting society which will touch our lives all for the better, while also enabling new avenues for destruction to enter into this world.

In May 2015, the US Government proposed amendments to its International Traffic in Arms Regulations (ITAR) to choke off distribution of 3D printable gun models as part of the President's Export Control Reform (ECR) initiative. If implemented, these changes would hurt any individual's or group's ability to share most gun-related design files online, increasing chances of legal consequences **[*35*]**. From the 3D printing and strategic trade controls standpoint, the most interesting changes come by way of the new revised definition proposed by the US government for 'technical data,' which is stated thus: "Paragraph (a)(1) also sets forth a broader range of formats that 'technical data' may take, such as diagrams, models, formulae, tables, engineering designs and specifications, computer-aided design files, manuals or documentation, or electronic media, that may constitute 'technical data'". Furthermore, a proposed revision to the term 'required' in ITAR would make any export of information regarding the creation of a particular weapon as serious of a crime as the export of the weapon itself and could result in millions of dollars in fines or even imprisonment. For example, it would be illegal to make the digital blueprints for a 3D model of a gun available on the internet via forums, Youtube, social media, or in any other manner **[*35*]**. The journey of a thousand miles begins with a single step, as they say, and this seems to be that step, and one in the right direction.

The question often arises as to why a belligerent state or a terrorist outfit would resort to 3D printing nuclear components and other smaller weapons, when they could perhaps steal nuclear and radiological material or create improvised explosive or nuclear devices. I argue that while it is true that terrorists may resort to those means, 3D printers considerably reduce manufacturing time and cost effectiveness. Also, while it may be just one more technological addition in the increasingly sophisticated 21st century, 3D printing certainly provides another means to create weapons of mass destruction in the future. Prevention and precaution are better than cure, and there may even be no cure for certain acts of terrorism, especially when they involve highly damaging nuclear material.

Furthermore, many transactions which traditionally required physical control by Customs and other enforcement agencies at international borders are likely to undergo a sea change if blueprints of various

3D printed products are transferred via the internet. As physical controls become less effective, intelligence agencies must increasingly work to secure the digital borders. A malevolent actor who has a printer and access to raw materials would still require advanced software and digital designs to create dangerous weapons. New production software shall thus become some of the most highly prized and classified secrets of governments. Arms control may become highly difficult, if not impossible. Weapons could be far more easily disguised. Terrorists could lose their dependency upon developed countries for their supplies, as highlighted earlier in the examples of replication of military equipment and the irrelevance of international clandestine smuggling routes. There may also be further implications for counterfeiting and anti-counterfeiting **[*39*]**. Unless there is effective monitoring of 3D printing code capabilities, a terrorist group with the machines, blueprints and printing "ink," or material, may be able to re-arm almost at will. Such possibilities have led to terms such as "Open Source Jihad" gaining currency. In 2010, the terror group al Qaeda released an article in its online magazine 'Inspire' which provided directions to manufacture a bomb in the family kitchen. It was a watershed moment. Though the kitchen bomb may be rudimentary, it leads one to worry what might happen when bomb designers as well as bombers may both have 3D printers. In that case, a far superior device may become easily accessible **[*40*]**.

Three-dimensional printers are poised to become a classic dual-use technology and thus hard to limit without curtailing their many benefits. We may have to completely rethink trade control law and enforcement **[*41*]** and begin working on the issue with immediacy. Humanity appears to be on the brink of a manufacturing revolution and a complete paradigm shift, where strategic trade control laws may become almost unenforceable. The need of the hour is, therefore, for security agencies globally to acquire topical training and equipment to prevent the harm that this new technology could one day cause. The need is also for technical and policy-making communities to ensure that sensitive technologies such as this remain in the right hands. The MECRs should introduce necessary controls to this end. The United States, the EU and its member states, Japan and China—the path-breakers in the world of 3D printing—should also consider introducing strategic trade control laws based on the parameters described above. Manufacturers and retailers would also be wise to keep an eye on the ongoing story of 3D printing to ensure they are up to date with the evolving strategic trade control laws.

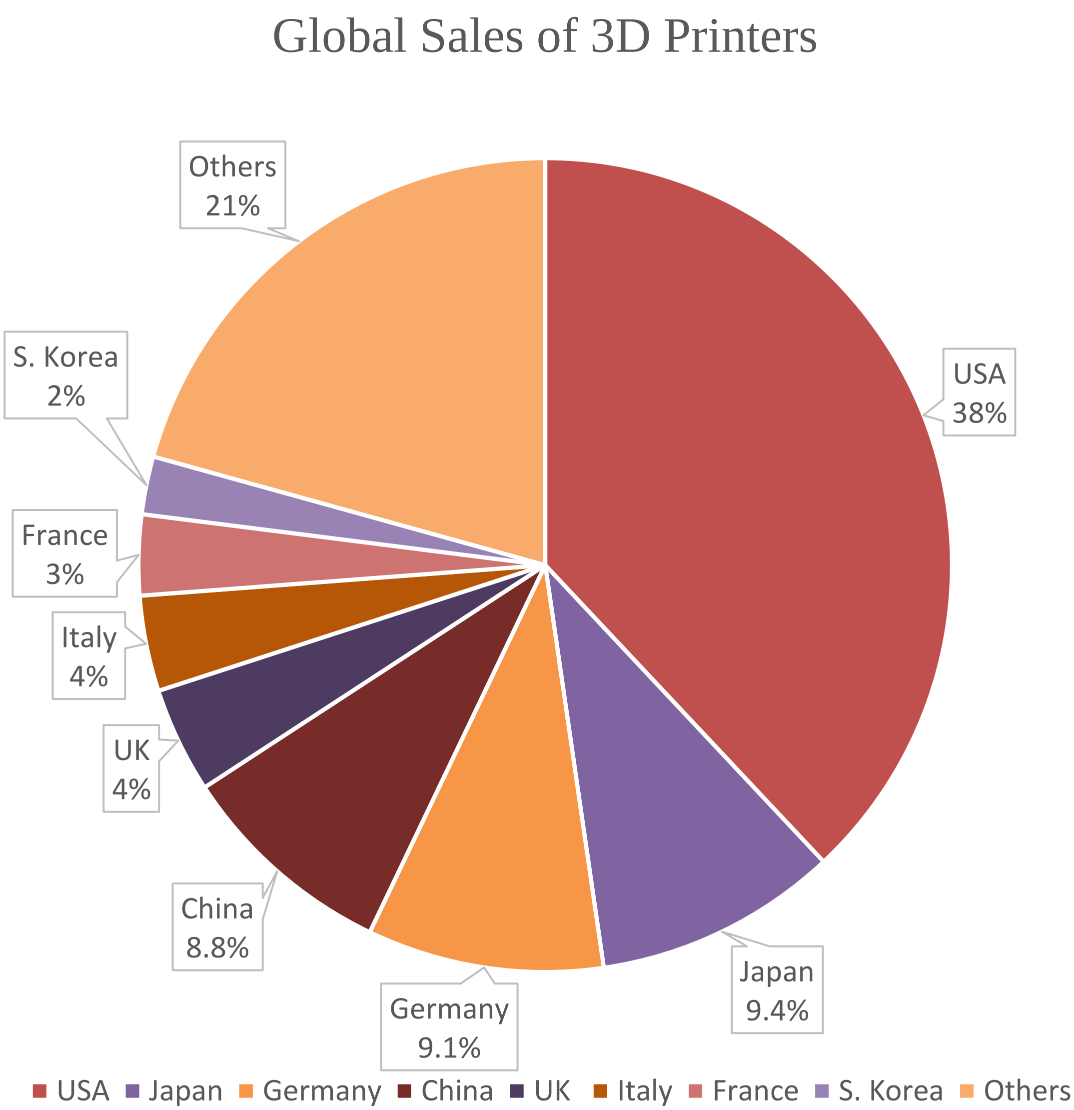
XV. ANNEXURE I

The following is a brief timeline of 3D printing to inform the reader of the history of 3D printing and update the reader on its current state:

- **1981-** Hideo Kodama of Nagoya Municipal Industrial Research Institute publishes the first account of a working photopolymer rapid prototyping system.
- **1984-** Charles Hull (founder of 3D systems) invents stereolithography (SLA) – which is patented in 1987. The technology allows one to take a 3D model and use a laser to etch it into a special liquid (photopolymer).
- **Late-1980s-** Emanuel Sachs of the Massachusetts Institute of Technology (MIT) with his team invents 3D printing and patents it [Patent No. 5204055] **[*33*]**.
- **1992-** 3D systems produce the first stereolithography (SLA) 3D printer/resin printer machine. The startup company DTM, which was acquired in 2001 by 3D Systems, produces the first SLS machine in the same year. This machine is similar to SLA technology but uses a powder (and laser) instead of a liquid.
- **2000-** The first multi-colour 3D printer was engineered by Z Corp. this year.
- **2008-** The first 3D prosthetic leg is produced. Further, Shapeways – a website market for 3D models – launches. It is much like Amazon or Ebay, where individuals can upload 3D models of objects which can be bought or sold online. Shapeways is a Dutch-founded, New York-based 3D printing marketplace and service startup company. As of June, 2012, Shapeways printed and sold over one million user-created objects **[*42*]**. Provided one has a 3D printer at home, it is possible to print out the Shapeways offerings.
- **2013-** Cody Wilson of Defense Distributed is asked to remove designs for the world's first 3D printed gun (made of plastic) and the domain is seized. It was classified under Category I of United States Munitions List (USML), which deals with firearms and a violation of the International Traffic in Arms Regulations (ITAR). The ITAR controls the export and import of defence-related articles and services on the USML **[*43*]**. These regulations implement the provisions of the Arms Export Control Act (AECA) and are described in Title 22 (that of Foreign Relations), Chapter 1 (Department of State), Subchapter M of the Code of Federal Regulations. Any company that manufactures, sells, or exports defence items such as guns, dual-use items (with either civilian or military applications) like aircraft engine parts, or related technical information, requires a registration with the US Dept. of State and export licenses for any restricted items. The plans were downloaded over 100,000 times in the two days before the US Department of State demanded that Defense Distributed retract the plans **[*44*]**. While the rapid downloading of this CAD file exhibits the popularity of firearms and resistance to certain laws, this can also be perceived as an example of how challenging it is to control a CAD file. The CAD file could then easily be shared privately via email or posted on a multitude of file-sharing websites, including those on the dark web or deep web. This would make the file itself impossible to remove from the Internet entirely as it would have proliferated on myriad torrent sites. The dangers associated with proliferation of maleficent technological knowhow are real. Traditional Customs techniques of inspection at the border may collapse before a virtual CAD onslaught and a new approach needs to be figured out by Customs and global trade/licensing agencies putting their heads together.
- **2014-** Boeing patents the first 3D printed part, a casing for a compressor inlet temperature sensor, which will be used in the BE90-94B jet engine on Boeing 777 aircraft **[*45*]**.

- **2015-** BMW makes a high-precision water pump wheel in a powertrain for their vehicle. This component is subject to high stresses, consists of an aluminium alloy and has previously proven its worth in the tough environment of motorsports **[*46*]**; Details emerge of a miniature 3D printed jet engine from the US multinational firm General Electric that can rotate at 33,000 rpm—a similar magnitude to that required for uranium-enriching centrifuges **[*47*]**. The analogy drawn here intends to draw attention to the fact that both the nuclear and aerospace industries require top-quality, high strength components; hence, 3D printing could soon be applicable to the production of strategic trade-controlled items that are part of the nuclear fuel cycle.
- **2017-** Mouse ovaries in Northwestern University; first residential house in Moscow; micro-camera with eagle-eye vision for use in drones.

XVI. ANNEXURE 2



Source: Wohlers Report, 2014

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