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Behind the Curve

New Technologies, New Control Challenges

Edited by

Benjamin King and Glenn McDonald



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The Small Arms Survey

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The objectives of the Small Arms Survey are: to be the principal source of public information on all aspects of small arms and armed violence; to serve as a resource centre for governments, policy-makers, researchers, and activists; to monitor national and international initiatives (governmental and non-governmental) on small arms; to support efforts to address the effects of small arms proliferation and misuse; and to act as a clearinghouse for the sharing of information and the dissemination of best practices. The Survey also sponsors field research and information-gathering efforts, especially in affected states and regions. The project has an international staff with expertise in security studies, political science, law, economics, development studies, sociology, and criminology, and collaborates with a network of researchers, partner institutions, non-governmental organizations, and governments in more than 50 countries.

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Abbreviations and acronyms

ABS	Acrylonitrile butadiene styrene
ACP	Automatic Colt pistol
AECA	Arms Export Control Act (United States)
AM	Additive manufacturing
ATF	Bureau of Alcohol, Tobacco, Firearms and Explosives (United States)
BJP	Binder jet printing
CAD	Computer-aided design
CCTV	Closed-circuit television
CNC	Computer numerical control
CoreIMS	Core Inventory Management System
CQB	Close Quarter Battle
DMLS	Direct metal laser sintering
DMR	Designated Marksman Rifle
DPM	Direct part marking
DTCC/END	US Department of State's Bureau of Political Military Affairs, Office of Defense Trade Controls Compliance, Enforcement Division
DTTS	Defense Transportation Tracking System
EBF	Electron beam freeform fabrication
EBM	Electron beam melting
ECSM	Electronically controlled safety mechanism
EDM	Electrical discharge machining
EGLM	Enhanced Grenade Launcher Module
EN	Electroless nickel
FDM	Fused deposition modelling
FFF	Fused filament fabrication

FFL	Federal Firearms License (United States)
IFP	Industrial Fingerprint
ISACS	International Small Arms Control Standards
ITAR	International Traffic in Arms Regulations (United States)
ITI	International Instrument to Enable States to Identify and Trace, in a Timely and Reliable Manner, Illicit Small Arms and Light Weapons ('International Tracing Instrument')
JORD	Joint Operational Requirements Document
MGE	Meeting of Governmental Experts
MIM	Metal injection moulding
OSCE	Organization for Security and Co-operation in Europe
PEEK	Polyether ether ketone
PLA	Polylactic acid
PoA	Programme of Action to Prevent, Combat and Eradicate the Illicit Trade in Small Arms and Light Weapons in All Its Aspects ('Programme of Action')
POM	Polyacetal
PSSM	Physical security and stockpile management
PVC	Polyvinyl chloride
PVD	Physical vapour deposition
RFID	Radio frequency identification
SCAR	Special Forces Combat Assault Rifle
SHS	Selective heat sintering
SLA	Stereolithography
SLS	Selective laser sintering
SOCOM	(US) Special Operations Command
SOPMOD	Special Operations Peculiar Modification
SPC	Special Purpose Cartridge
STL	Stereolithography file format
UN CASA	United Nations Coordinating Action on Small Arms
UNGA	United Nations General Assembly
UV	Ultraviolet

About the authors and editors

N.R. Jenzen-Jones is a military arms and munitions specialist and security analyst focusing on current and recent conflicts, and is the director of Armament Research Services. He has produced extensive research and analysis on a range of small arms and light weapons and small arms ammunition issues, and has also provided technical assessments of ordnance, incendiary weapons, cluster munitions, and conventional arms proliferation. His other research fields include counter-piracy, counter-narcotics, and the exploitation of technical intelligence. He is a certified armourer and ammunition collector, and a member of the International Ammunition Association and the European Cartridge Research Association.

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Foreword

Ubiquitous in every aspect of modern life, technological progress is affecting weapons and weapons systems, including small arms and light weapons. New manufacturing trends in firearms include the use of new materials such as polymer frames, modular weapons, or the possibility of 3D printing of parts or whole weapons. For the control of small arms and light weapons according to international conventions and documents—such as the International Tracing Instrument or the UN Programme of Action—these technologies translate into new challenges: How can one ensure that modular weapons remain traceable? How can the durability of markings on polymer frames be guaranteed? And how can the uncontrolled spread of manufacturing via 3D printing technologies be avoided?

This study, *Behind the Curve: New Technologies, New Control Challenges*, funded by the German government, takes stock of technological trends in weapons manufacturing and explores possible ways ahead. It builds upon the report of the UN Secretary-General on recent developments in small arms and light weapons technology and the implications thereof for the International Tracing Instrument. The publication proposes solutions to the given challenges. It also addresses new, technology-driven opportunities in tracing and stockpile management, such as the use of pin codes, palm-print scanner recognition, microstamping, radio frequency identification, and intelligent stockpile management systems.

More consistent use of electronics may lie ahead. While electronics dominate in financial networks, transport systems, communications, medical equipment, and numerous other aspects of modern life, surprisingly little use has been made of them so far for weapons control purposes. The German government has introduced the electronically encrypted tracing data of small arms and light weapons as a precondition to their export. The next logical step could be the coupling of a weapon's functionality with its electronics. I believe it is just a matter of time before such technologies spread.

The alarming increase in security crises and violent extremism in many parts of the world may lend additional weight to this conjecture.

I would like to thank the Small Arms Survey for this outline of current technological trends in weapons manufacturing. I hope this study will also serve as stimulation to the reader for the next step in small arms and light weapons control technology—contributing, inter alia, to discussions at the Meeting of Governmental Experts in 2015, within the framework of the UN Programme of Action.

With several hundred thousand deaths worldwide occurring every year due to the use and abuse of small arms, these issues remain extremely pertinent.



Antje Leendertse

**Federal Government Commissioner for Disarmament and Arms Control
January 2015**

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Introduction

Benjamin King and Glenn McDonald

Recent developments in small arms manufacturing, technology, and design pose a series of challenges to the implementation of existing control instruments, such as the UN Small Arms Programme of Action (PoA) (UNGA, 2001) and the International Tracing Instrument (ITI) (UNGA, 2005). Two such developments were identified at the PoA's first Open-ended Meeting of Governmental Experts (MGE₁) held in 2011: the use of polymers to produce firearm frames and receivers, and modular weapon design. Since 2011, the production of firearms using additive manufacturing methods (3D printing), particularly by unlicensed individuals, has sparked concern among policy-makers and law enforcement officials. Yet technology can also provide new, better options for small arms control, including for weapons marking and record-keeping, for stockpile management, and to prevent unauthorized use.

These issues are reviewed in a report that the UN Secretary-General produced, at the request of the UN membership, just before the PoA's Fifth Biennial Meeting of States held in 2014 (UNGA, 2014a). The next step in the process is the second MGE (MGE₂), to be convened at UN headquarters in New York, from 1 to 5 June 2015. As mandated by the UN General Assembly, the meeting will consider 'recent developments in small arm and light weapon manufacturing, technology and design', including '[p]ractical steps to ensure the continued and enhanced effectiveness of national marking, record-keeping and tracing systems in the light of such developments' (UNGA, 2014c, para. 6; 2014b, paras. 40a–b).

This Occasional Paper, *Behind the Curve: New Technologies, New Control Challenges*, which was prepared with the financial support of the German Ministry of Foreign Affairs, covers the four above-mentioned areas: polymer frames, modular weapons, 3D printing, and the use of new technologies for improved small arms control. Under each topic, the publication reviews relevant control challenges and options and, like the UN report, can help UN

member states prepare for MGE2—including on the critical matter of how to respond to the new technologies and challenges. Initial findings of this study were released as background papers at the Fifth Biennial Meeting of States in June 2014 and were subsequently presented as a draft publication at the sixty-ninth session of the UN General Assembly's First Committee on Disarmament and International Security, in October 2014. The side-event, titled 'Behind the Curve: New technologies and small arms control' took place at UN headquarters, New York, on 19 October 2014.

The four chapters of the publication review each of the four topics in turn, beginning with a discussion of **polymer frames**, in Chapter I, by **Giacomo Persi Paoli**. Given the light weight and low cost of polymers, gun manufacturers are increasingly using them in the production of firearm parts, including the frame of many handguns marketed to governments and civilians. Yet, in contrast to metal, it is often difficult to mark polymer firearm frames durably, as the ITI prescribes, especially after the time of manufacture (UNGA, 2005, para. 7). Arms traffickers seeking to make a polymer gun untraceable can simply remove the visible, factory-marked serial number from the frame. As described in this chapter, the ITI takes little account of the specificities of polymer firearms. Guidance is needed on such issues as the marking technologies applicable to polymer firearms, the use of metal tags on such weapons, and the depth and location of markings to be made directly to polymer parts.

Chapter II, also by **Giacomo Persi Paoli**, describes how armed forces in some countries are exploring **modular design** rifles as 'all-in-one' replacements for different rifle types and models. The upper or lower receiver of a modular rifle typically serves as a core section around which all, or almost all, other key parts and components can be changed in order to reconfigure the rifle to meet different operational needs. (For example, one can change the barrel or calibre, so as to optimize the way in which the weapon engages its target at different distances.) Despite such advantages, modular weapons erode the distinction between the weapon and its components, complicating unique identification and record-keeping, which are essential elements of weapons tracing. The central question for policy-makers is, in fact, how to adapt marking and record-keeping practices so that a modular weapon can

be uniquely identified—and traced—at any point in its life cycle, irrespective of any potential changes in its configuration.

As described in Chapter III, by **N.R. Jenzen-Jones**, an increasing number of firearm producers are using additive manufacturing (**3D printing**) technology to produce gun components and accessories. While the high cost of this technology currently precludes the mass production of 3D-printed metal firearms, some hobbyists and craft producers are using the technology to produce functioning, although basic, polymer firearms. Current norms, both national and international, including those contained in the PoA and ITI, are largely adequate for the control of consumer-produced 3D-printed guns, but the application of these norms is more difficult—largely because of the diffusion of relatively powerful 3D printing technology to individuals and small groups. Unmarked, untraceable, and less easily detected by security screening devices, 3D-printed guns are potentially attractive to criminals and non-state armed groups. Nevertheless, on any current measure of relative cost and performance, firearms produced using traditional manufacturing techniques, including craft-produced weapons, easily outperform their 3D-printed counterparts. Governments have a clear interest in using the PoA and ITI to enhance their control over 3D-printed guns. Yet the key challenges in the illicit market remain those posed by traditionally manufactured firearms.

As mentioned already, technologies that are new—or new to the firearms industry—including the use of polymer, modular design, and 3D printing—can complicate small arms control. Nevertheless, as described in Chapter IV, written by **Matt Schroeder**, **new technologies** can also improve marking, record-keeping, and tracing, strengthen stockpile security, and prevent unauthorized use, provided, that is, critical barriers to their adoption and diffusion can be overcome. Chapter IV reviews the possibilities such technologies present for enhanced small arms control, and outlines the barriers that may hinder their uptake, including the cost of establishing supporting infrastructure (databases and networked IT) and, in some cases, concerns about reliability.

In sum, traditional firearms technology is proving surprisingly resistant to the changes that have recently transformed other products and industries;

the critical control challenges remain those posed by small arms produced by traditional methods. Ultimately, the basics of weapons marking, record-keeping and tracing, stockpile management, and diversion prevention, as defined in the PoA and ITI, remain fundamental. Nevertheless, important technological changes are also affecting the firearms industry. Governments have a clear interest in determining how to interpret and implement the PoA and ITI in order to meet the challenges posed by these recent developments in small arms manufacturing, technology, and design. MGE2 provides the UN membership with an opportunity to share relevant information and, most importantly—drawing on the UN Secretary-General’s report, this publication, and their own experiences—to develop specific guidance regarding the application of the PoA and ITI to the new challenges. 📖

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I. Techno-polymers in firearms manufacturing: Challenges and implications for marking, record-keeping, and tracing

Giacomo Persi Paoli

Introduction

Over the last three decades, the arms industry has been characterized by a transition from metal to polymers in the manufacture of an increasing number of firearm parts and components—a trend that shows no signs of abating. Motivated to improve performance and to reduce costs, the industrial sector, including the arms industry, continues to prioritize research and development on new materials (Penny, Hellgren, and Bassford, 2013).

Despite this development, the intrinsic differences between metal and polymers, and the related technical challenges for marking them, were overlooked when the UN Firearms Protocol¹ and the International Tracing Instrument (ITI)² were negotiated. To date, these agreements represent the only international instruments providing specific indications—either as requirement or as recommendation—on firearm marking, record-keeping, and tracing. Yet the oversight regarding an established industrial trend poses important challenges to the implementation of key provisions of these instruments.

The relevance of new technologies is acknowledged and highlighted in the 2014 report of the UN Secretary-General on recent developments in small arms and light weapons manufacturing, technology, and design and their impacts on the implementation of the ITI. The report, produced based on a mandate from the 2012 Programme of Action Review Conference,³ states:

Since the adoption in 2005 of the International Instrument to Enable States to Identify and Trace, in a Timely and Reliable Manner, Illicit Small Arms and Light Weapons, new weapon design and production methods have emerged that

could have consequences for international efforts to address the illicit trade in small arms. Those include the use of non-traditional materials, such as polymers, and modularity in weapon design (UNGA, 2014a, p. 1).

This paper supports discussions among UN member states on '[t]he implications of recent developments in small arm and light weapon manufacturing, technology and design for effective marking, record-keeping and tracing' (UNGA, 2014b, para. 40(a)), in particular at the 2015 Open-ended Meeting of Governmental Experts (MGE). More specifically, the study provides an overview of the key elements related to the use of industrial polymers in arms manufacturing, highlighting the challenges that such materials pose to the effective implementation of the ITI and the Firearms Protocol. Although several firearms parts and components are often manufactured with one or more types of polymer, this paper focuses on polymer frames and receivers as they typically bear unique markings that are critical for the unique identification of a weapon (UNGA, 2005, art. III, para. 10).

Techno-polymers: history, definitions, and characteristics

A polymer is a large molecule or macromolecule, composed of many repeated sub-units, known as monomers, which are combined through a process called polymerization. Polymers possess a wide spectrum of unique properties; they occur naturally in DNA or proteins that are fundamental to biological structure and function, or synthetically, such as in plastics (McCrum, Buckley, and Bucknall, 1997; Painter and Coleman, 1997).

While natural polymers are the basis of life, the development of synthetic polymers is relatively recent. Crucial, well known polymers that have been developed since the early days of polymer science include vulcanized rubber, Bakelite, neoprene, nylon, polyvinyl chloride (PVC), and polystyrene (Carraher, n.d.).

During the Second World War, due to shortages of raw materials caused by increasing wartime demands, scientists started to explore alternative materials that were easier to access and better performing. Related developments included the use of materials such as aromatic nylons ('aramids'),

Kevlar® (capable of stopping a bullet and used as tyre cord), and Nomex® (used to make fire-resistant garments) (Carraher, n.d.).

In the last 30 years, the development of new synthetic polymers and the improvement of existing ones have resulted in the increasingly frequent replacement of metal with high-performance polymers, sometimes referred to as ‘techno-polymers’, for industrial applications. Examples of the most compelling incentives identified for this substitution include a reduced component (or part) weight and an overall reduction in costs (Sauer, 2011).

From an industrial perspective and in particular in the context of arms manufacturing, several chemical, physical, and mechanical properties of polymers are of particular interest:

- 1) The **tensile strength** quantifies how much stress the material will endure before failure.
- 2) The **elasticity** is the property of solid materials to return to their original shape and size after the forces deforming them have been removed. In the case of polymers, particularly relevant is Young’s modulus of elasticity: a numerical constant that describes a material’s response to stresses applied to opposite faces (pulling an object apart or pushing it from opposite sides).
- 3) The **creep resistance** quantifies a material’s ability to resist, at different temperatures, any kind of distortion when under a load, over an extended period of time.
- 4) Other relevant properties include: **temperature resistance** and, more importantly, **water absorption rate**.

To enhance their strength and elasticity, polymers are often reinforced with different kinds of fibres (such as glass, carbon, or aramid). The extent to which strength and elasticity are improved in a fibre-reinforced polymer depends on the mechanical properties of the two components, their volume relative to one another (usually expressed in terms of percentage), and fibre length and orientation (Smallman and Bishop, 1999).



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Images 1 and 2. **An example of a Kevlar-reinforced polymer 80 per cent lower receiver for AR-15 (left) and a ‘first generation’ Glock 17 with the slide locked back (right).**

The list of synthetic polymers available for industrial application is considerable. In the context of arms manufacturing, the most common polymers—reinforced or otherwise—occur in the following families:

- polyamide (PA6 and PA6.6);
- polyarylamide (PARA, usually 40–60 per cent fibre-reinforced);
- polycarbonate;
- polyacetal (POM); and
- thermoplastics (TPU/TPV).⁴

These polymers mentioned above are all available on the global market. Main commercial suppliers (including Bayer Material Science, Solvay Plastics, and DuPont) offer several products within these families of polymers. In a bid to further enhance product performance, arms manufacturers sometimes support suppliers in their development of new polymers over which they may then assert exclusive rights of use.

Different companies used various polymers with limited success between the late 1950s and early 1980s to produce different firearm parts and components.⁵ The first polymer-frame handgun to be successfully marketed worldwide and well received by different user communities was introduced by Glock in 1981 (G17 model). Its success resulted in a progressive transition to polymers, soon followed by other arms producers (Brogi, 2014).

A comparative analysis of polymers and metals in arms manufacturing

Economic and industrial perspectives⁶

Costs

Given that polymers have been increasingly used to replace metal in the production of different firearm parts, a key indicator of a difference between polymers and metals is cost per part.

Although cost benefits vary among countries and producers (with differing costs of labour and raw material), intensive use of polymers allows a cost-per-part reduction of as much as 40 per cent, on average. Depending on the firearm type and model, this saving leads to an overall cost reduction of 10–20 per cent per weapon, on average.

Several factors contribute to the final cost of producing a firearm. Although the use of polymers over metals significantly reduces the cost of raw materials, it entails higher non-recurring costs. For example, because it is impossible to adjust a polymer part post-manufacture and impractical to modify the moulds used to generate standard parts, ad hoc moulds need to be developed in order to meet specific requirements not met by the 'standard' part. In most cases, ad hoc moulds are useable only in the context of the specific contract for which they were developed. Consequently, their cost cannot be recovered by using them for production runs bearing different requirements.

Industrial set-up

From an industrial perspective, the transition from metals to polymers calls for numerous changes ranging from the supply of raw materials to the production process. In particular, the equipment used to manufacture polymer parts is completely different from that required to make metal parts.

The process most commonly used to manufacture high volumes of the same polymer object is injection moulding. Once the desired object is designed, usually by industrial designers or engineers, moulds are made to replicate its features exactly. Given how expensive moulds are to manufacture,



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Image 3. Another example of a handgun featuring a polymer frame, the FNH five-seveN® pistol. Note the metal tag embedded in the front part of the frame, bearing the serial number.

they are best suited to mass production of parts (in their thousands). Moulds are made of various kinds of materials, usually hardened steel, pre-hardened steel, aluminium, and/or a beryllium-copper alloy. The choice of material for the mould usually results from a cost-benefit analysis: steel moulds are more expensive to create, but have a longer lifespan which may offset the higher initial cost spread over the higher number of parts that can be manufactured before the mould wears out (Rosato, Rosato, and Rosato, 2000, p. 176).

The injection-moulding process consists of the high-pressure injection of a raw material (in this case, melted polymer) into the mould. The melted polymer takes the shape of the mould and, because the mould is cooler than the polymer, the latter solidifies rapidly (Groover, 2010, p. 286). Injection moulding can now be applied, including in arms manufacturing, to produce metal parts via a dedicated process called metal injection moulding (MIM). Current capabilities of equipment and cost considerations, however, normally limit the use of MIM to the production of small, complex parts.

The types of machinery used to produce polymer parts and used in the MIM process differ substantially from the machinery used to manufacture metal parts. This discrepancy leaves arms manufacturers with the options of:

- **Outsourcing** the production of polymer parts to specialized (sometimes local) subcontractors. Manufacturers which already own complex production lines to produce metal parts often opt for this solution, because it would be too costly to fully integrate new equipment for polymer moulding into their existing processes.

- **Developing in-house capability** is more viable for smaller or recently established companies which can integrate new polymer production equipment and processes into their set-up planning.

Operational or user perspective

In addition to the above-mentioned economic and industrial considerations, it is important to note that polymers and metals differ significantly from an operational (user) perspective.

The most striking difference is weight. A handgun frame made of polymer can be up to 85 per cent lighter than a traditional metal handgun frame. The overall gun weight can be up to 40 per cent lighter, for example, making a fully loaded handgun with a polymer frame about the same weight as a traditional metal handgun *without* its magazine (Brogi, 2014). This difference in weight also alters its distribution which, in combination with the greater elasticity of polymers over that of metals, serves to reduce felt recoil.

A third advantage of polymers is the possibilities they offer for ergonomic design of handguns and rifles resulting in improved comfort, accuracy, and safety. Such designs may offer thumb rests, facilitate proper grip, allow for easy and comfortable use by both right-handed and left-handed users, and limit the risk of the firearm getting tangled in a holster or clothes when drawn. By optimizing the user-to-weapon interface, ergonomic design increases accuracy in shooting.

Polymer frames can be composed of a single part (e.g. handgun frames) or of two 'shells'; the latter is most commonly used in rifles, particularly those featuring a 'bullpup' design (see Images 4 and 5).⁷ According to the ITI, frames/receivers are considered 'essential or structural' components, the destruction of which 'would render the weapon permanently inoperable and incapable of reactivation' (UNGA, 2005, para. 10). A rifle shell-type frame or receiver, however, is easily replaced when damaged (Jacobs, 2013).

Additional properties of polymers that confer advantages over the use of metal include: resistance to corrosion, resistance to chemicals and lubricants, electric and thermal insulation, and low-maintenance requirements.



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Image 4 and 5. **Bullpup rifles usually feature polymer ‘shells’ that maximize the benefits of an ergonomic design: an FNH F2000 (left) and the related polymer shells (right).**

Finally, from an operational and user perspective, despite the above-mentioned advantages, firearms containing polymer parts may be more susceptible to accidental damage⁸ than those that are completely metal-built. This risk applies predominantly to those firearms fabricated with a combination of metal and polymer parts, in particular at junction points: where the connection between different materials with different physical properties may become a critical vulnerability.

Implications for marking

Marking primarily serves to provide unique identification for each small arm or light weapon. This in turn facilitates the creating and maintaining of national records and, ultimately, the tracing of weapons.⁹

Accordingly, the ITI and the Firearms Protocol contain provisions specifying the physical characteristics, location, content, and timing of marking. In general terms, without reflecting the specific nuances of each instrument, they can be summarized as follows:

- **A unique marking** should be applied to an essential or structural component of the firearm, on an exposed surface, conspicuous without technical aids or tools, easily recognizable, readable, durable, and, as far as technically possible, recoverable.
- **Marking at the time of manufacture** should include the name of the manufacturer, the country of manufacture, and the serial number; along with

such additional information as the year of manufacture, firearm type or model, and calibre;

- **Post-manufacture marking** should include import marking (country and year of import); marking at the time of transfer from government stocks to permanent civilian use; marking of firearms in the possession of government, armed, and security forces; and unique marking, or prompt destruction, of illicit firearms found on national territory.

Despite the relatively widespread use of polymers in firearm manufacture at the time when the Firearms Protocol and the ITI were negotiated, they pose certain challenges to the implementation of both instruments. These challenges, in turn, threaten the traceability of weapons.

At the time of manufacture, common markings—such as the manufacturer’s name, logo, and all other marks uniform to firearms—are directly incorporated in the mould for the polymer part. Yet each serial number must be unique. Including a serial number in the mould would call for one unique mould per firearm—which is clearly impractical, in terms of cost and time. On the other hand, any other marks applied to the polymer part after it is made, such as serial numbers, can easily be removed or altered (see ‘Marking method’ below).

In 2001 the United States issued updated requirements for firearms identification markings, applicable to licensed importers and manufacturers (US Department of Treasury and ATF, 2001). They included the requirement that manufacturers embed a metal tag featuring a stamped serial number in firearms with polymer frames in order to impede the sanitization (removal or alteration) of markings. Manufacturers place such tags in different locations, depending on the model and type of weapon, and usually stamp the serial number on the tag *before* it is inserted into the frame. As noted above, however, the ITI specifies that:

A unique marking should be applied to an essential or structural component of the weapon where the component’s destruction would render the weapon permanently inoperable and incapable of reactivation, such as the frame and/or receiver. (UNGA, 2005, para. 10)

The embedding of metal tags in a polymer frame may thus not constitute a permanent marking solution in accordance with the ITI. How easy it is for a person to remove metal tags from polymer frames without causing critical damage varies widely among firearm models, types, and makes, although it is possible to do. It is often quicker and easier to deface a serial number on a tag, as happens with traditional metal frames. With polymer frames there is an additional risk that the tag be removed completely (see Image 6).



Image 6. A poorly attached metal tag can be removed easily. In the example illustrated by this image, the Firearms Technology Branch of the US ATF tested a sample of a commercial lower receiver against the federal requirements for marking. The serial number was removed easily when a hammer and screw driver were used to peel the sheet off the metal insert. This action took about a minute and caused no damage to the receiver.

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Further challenges arise with respect to post-manufacture marking, specifically as prescribed in the ITI and the Firearms Protocol. Under current practice, metal tags are usually sized to accommodate only serial numbers, meaning that any additional post-manufacture marks must be applied directly to the polymer frame. This creates two key limitations:

- 1) **Marking method:** The manufacture of polymer frames does not involve the heat and surface treatments usually applied to metal frames at the very end of their manufacturing process to increase their resistance to wear. Polymer frames can thus be marked, post-manufacture, without damaging the finish that is often applied to metal frames. Nevertheless, although the ITI indicates that the choice of marking method ‘is a national prerogative’ (UNGA, 2005, para. 7), due to the physical characteristics of polymer material, marking options are limited once the firearm is assembled. The two methods appropriate for adding post-manufacture marks are laser engraving and, with certain limitations, dot-peen (micro-percussion) (Persi Paoli, 2010). Although both methods can be used to apply

marks on polymer parts, they must satisfy certain technical requirements (relating to the depth and location of the mark) to ensure that the marks meet, to the extent possible, the ITI's criterion of 'durability' (UNGA, 2005, para. 7).

- 2) **Recoverability of the mark:** The recovery of an intentionally removed or altered mark is often crucial to the successful tracing of a weapon. When metal is marked with the stamping method, subsequently altered or erased marks can frequently be recovered through a complex forensic process in which the altered physical structure of the metal is analysed. Currently however the recovery of a mark made on polymer and subsequently removed or altered is much more difficult, though not strictly impossible (Persi Paoli, 2010).

Box 1. Providing guidance: the International Small Arms Control Standards

The International Small Arms Control Standards (ISACS), produced by the United Nations Coordinating Action on Small Arms (UN CASA) mechanism in collaboration with a broad and diverse group of experts and organizations, address the issue of polymer frames and receivers. ISACS provide relevant provisions, specifically from the module on marking and record-keeping, as follows:

- In relation to the **unique markings applied at the time of manufacture**, ISACS recommends for non-metallic frames to include the application of the marks:
 - (...) to a metal plate permanently embedded in the material of the frame in such a way that:
 - a) the plate cannot be easily or readily removed; and
 - b) removing the plate would destroy a portion of the frame (UN CASA, 2012, cl. 5.2.1.1.4.)
- In relation to **import marking**, ISACS specify that such a marking should be applied on the metal plate or tag. If a metal plate is not present or there is insufficient space for it, the import mark can be applied directly to the polymer frame: choosing a location likely to minimize wear and tear, and also duplicating the import mark on a second, metallic part (UN CASA, 2012, cl. 5.3.3.2).
- With respect to the **marking method**, ISACS recommend the use of laser technology for all import marks. ISACS also include recommendations on the minimum depth such markings should have for both metallic and non-metallic frames (UN CASA, 2012, cl. 5.3.4).

While not covering all of the potential problems related to the use of polymers in firearms manufacturing, ISACS provide a sound foundation for accounting for this new trend in firearms manufacturing.

Given the widespread use of polymers in firearms manufacturing, the unavailability of the appropriate marking technology (e.g. lasers) could render certain marking norms impossible to fulfil, in particular those governing post-manufacture marking. The physical characteristics of polymers and the difficulty of marking them durably place severe limits on the recoverability of removed or altered marks, which in turn potentially thwarts tracing.

The commercialization of polymer lower receivers

The spread of polymers as a material of choice in the production of firearm parts has created a substantial market for lower receivers, especially in the United States and more specifically for the Colt AR15, which is prevalent in the US civilian market (*The New York Times*, 2013).

Several companies now offer branded lower receivers: some are in metal, but the majority come in different types of polymers. The analysis of these lower receivers that are commercially available to civilians is particularly relevant as it touches on another recent technology trend: additive manufacturing or 3D printing. While still in its infancy as far as arms manufacturing is concerned, this technology is being applied successfully to other industrial sectors. It has the potential to ‘privatize’, if not the production of complete firearms, the production of certain parts thereof, such as lower receivers (see Chapter III).

This chapter reviews some of the key issues relating to polymer lower receivers:

- who is producing and distributing them and how much they cost;
- the strengths and limitations of polymer lower receivers as compared to metal ones;
- how they are classified from an arms control perspective; and
- the implications thereof for firearms marking and record-keeping.

While it would be difficult to provide a complete list of producers of polymer lower receivers, open sources suggest that there are between six and nine main producers and a much higher number of licensed distributors (a few dozen) of metal lower receivers, and between eight and ten suppliers of polymer lower receivers offering various models ranging from USD 50 to 200 in price.¹⁰

Because polymer lower receivers cost less to produce, they are cheaper. Other advantages include an easier customization process that holds significant appeal in the civilian market in which suppliers operate. The lower cost of this customization, however, comes at the expense of reduced strength in several critical areas of the receiver, particularly the very rear part at which the receiver joins the stock. This area is subject to the greatest strain in the entire gun, since a relatively small piece of material is responsible for keeping all the parts aligned during the violent and repetitive movement of the different components involved in the firing action (Leghorn, 2014). Any fragility in this part, in particular stemming from lower quality plastic materials, hampers the function of the weapon as a whole. Variations in price between models reflect the measures taken by producers to counter this problem; such counter-measures include the use of higher quality polymers, such as Kevlar®, fibre-reinforced polymers, or the application of a ‘hybrid design’. This latter solution involves inserting a small block of metal in order to reinforce the area and decrease the likelihood of cracking (see Image 7; Leghorn, 2014).



Image 7. A Some polymer lower receivers include a small metal insert to reinforce a particularly weak junction area.

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Regarding the legal classification of lower receivers, including polymer receivers, according to the US Gun Control Act of 1968, the term ‘firearm’ refers to:

*(A) any weapon (including a starter gun) which will or is designed to or may readily be converted to expel a projectile by the action of an explosive, (B) **the frame or receiver of any such weapon;** (C) any firearm muffler or firearm silencer, or (D) any destructive device (US Congress, 1968, art. 921(a)(3); bold added).*

The US Code of Federal Regulations (CFR) provides a definition of ‘frame or receiver’:

***Firearm frame or receiver.** That part of a firearm which provides housing for the hammer, bolt or breechblock, and firing mechanism, and which is usually threaded at its forward portion to receive the barrel (US Government, 2014, 27 CFR, s. 478.11; bold added).*

As the US Gun Control Act makes clear, a complete lower receiver constitutes a ‘firearm’. For this reason, those lower receivers available for sale are usually ‘80% lower receivers’—essentially incomplete, as they require special tooling and skills in order to be considered a firearm (Tactical Machining, n.d.). In contrast to complete firearm receivers, 80 per cent lower receivers do not have to be sold or otherwise transferred only by a Federal Firearms License (FFL) holder.

Several suppliers of 80 per cent lower receivers have sought a determination from the US Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) to establish the legal status of their products. In general, ATF has held that an 80 per cent lower receiver does not reach the level of machining required to be classified as a ‘firearm’ under the Gun Control Act—among other reasons, because the fire-control cavity is often left solid (Gomez, 2014). While the unregulated status of 80 per cent lower receivers promotes competition and, presumably, product improvement among a larger number of producers, it also poses several challenges to arms control and, potentially, to safety.

From a safety perspective, as noted above, the ‘unfinished’ nature of the product means that special tooling and skills are needed to finish it. A user lacking the necessary equipment or skills could potentially damage the receiver, thereby posing a danger to anyone using the firearm that incorporates it.

From an arms control perspective, the ease with which lower receiver replacements can be purchased challenges marking and record-keeping in two ways:

- 1) Any marks applied by the firearm’s original manufacturer to the lower receiver will be lost when that part is replaced with another lower receiver.
- 2) While lower receivers marketed to civilians often carry their own marks, these do not always meet the same standards that duly licensed firearm

manufacturers are legally bound to comply with (e.g. may contain metal tags that are poorly attached to the receiver).

These two limitations apply mainly to 80 per cent lower receivers, but there have been examples of commercialized lower receivers bearing marks not compliant with US Federal law (Johnson, 2014).


Conclusion

Given their contribution to better performance and lower costs, industrial polymers or other composite materials are bound to gain an increasingly dominant role in the arms industry. Yet, given how they differ physically from metal, polymers risk impeding the implementation of key international norms for the marking of small arms and light weapons and, consequently, firearms tracing.

The ISACS module on small arms marking and record-keeping represents a sound, first attempt to tackle such matters, although it does not have the normative reach of the ITI or the Firearms Protocol. In order to ensure the continued or, better still, enhanced effectiveness of national marking, record-keeping, and tracing systems, and of relevant multilateral control instruments (in particular the ITI), states will need to address the following issues:

- A means of ensuring that manufacture and post-manufacture marks applied to polymer parts are in line with the marking provisions of the ITI, for example through the insertion of a metal plate or tag in the frame or receiver. This will include addressing topics such as: depth of the insertion, plate dimension and location, marking method, and the duplication of marks.
- The diffusion of marking technologies that would allow post-manufacture marks to be applied to polymers (e.g. laser engraving or micro-percussion), including related training.
- The development of new techniques for the recovery of marks on polymer parts that have been removed or altered.
- The inclusion of the manufacturers of polymer frames and receivers in small arms control discussions and initiatives, in particular those relating

to firearms marking, record-keeping, and tracing.

The 2015 MGE will provide governmental experts with an important opportunity to discuss the challenges arising from recent developments in firearms manufacturing, including those related to the use of new materials, such as polymers, and to identify some of the steps with which to address them. 

Endnotes

- 1 Full name: Protocol against the Illicit Manufacturing of and Trafficking in Firearms, Their Parts and Components and Ammunition, supplementing the United Nations Convention against Transnational Organized Crime. See UNGA (2001).
- 2 Full name: International Instrument to Enable States to Identify and Trace, in a Timely and Reliable Manner, Illicit Small Arms and Light Weapons ('International Tracing Instrument'). See UNGA (2005).
- 3 Full name: United Nations Conference to Review Progress Made in the Implementation of the Programme of Action to Prevent, Combat and Eradicate the Illicit Trade in Small Arms and Light Weapons in All Its Aspects. The PoA was held in New York, from 27 August to 7 September 2012.
- 4 Author interviews with representatives of the arms industry.
- 5 Several attempts were made between the 1950s and 1980s to market firearms featuring one or more polymer part. Nevertheless, before the introduction of the Glock, firearm user communities generally did not regard polymers highly. This scepticism on the demand-side of the market limited the scale of production and distribution of these early attempts to introduce polymers into firearms. Examples of early attempts include: the Remington Nylon 66, a semi-automatic carbine produced between 1959 and 1989, featuring a polymer stock and (shell) frame; the Heckler & Koch VP70, the first handgun produced between 1970 and 1989, featuring a polymer frame; and the Syn-Tech Exactor by Ram-Line, a handgun based on the Ruger Mark II design produced between 1980 and 1995, featuring a polymer frame (Brogi, 2014).
- 6 Unless otherwise specified, the information presented in this section is based on in-person interviews between the author and representatives of the arms industry, as well as on the analysis of responses to a questionnaire prepared by the author.
- 7 The bullpup design places the gun's action behind the trigger, in front of a short buttstock. This decreases the firearm's length and weight but the barrel length remains the same. Bullpups generally allow for a 25 per cent reduction in firearm length, which allows for better manoeuvrability in confined spaces (Dockery, 2007, p. 64).
- 8 Accidental damage results from unforeseen, unintentional, external, and violent causes, but excludes wear and tear or gradual deterioration with age.

- 9 As defined in the ITI, tracing is ‘the systematic tracking of illicit small arms and light weapons found or seized on the territory of a State from the point of manufacture or the point of import through the lines of supply to the point at which they became illicit’ (UNGA, 2005, para. 5).
- 10 Some specialized websites offer a list of possible suppliers, with summaries of their main characteristics. See, for example, AR15.com (n.d.).

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II. From firearms to weapon systems: Challenges and implications of modular design for marking, record-keeping, and tracing

Giacomo Persi Paoli

Introduction

In the early 2000s, a need arose for a more flexible type of military rifle that could be easily reconfigured to meet different operational requirements and accommodate a range of sophisticated accessories. This need led to the development of the so-called modular design for infantry rifles. The concept of modularity is simple: each rifle has a core section (the upper or lower receiver) around which the user can switch all other parts to obtain different configurations depending on requirements (Persi Paoli, 2013, p. 2).

Although modularity has progressed since the mid-2000s, the international community has to date paid only limited attention to its potential implications for arms control. For example, the architecture of modular weapons is based on a core section and a set of interchangeable parts and components, yet the provisions of the International Tracing Instrument (ITI)¹ largely focus on small arms and light weapons as a whole. The UN Firearms Protocol² mentions ‘parts and components’; however, its focus—for example in the marking provision (UNGA, 2001, art. 8)—lies primarily on firearms as a whole.

While the lack of measures to specifically address parts and components has limited impact in the case of standard firearms, it is particularly problematic in relation to modular weapons. The shortcoming is acknowledged in the 2014 report of the UN Secretary-General on recent developments in the manufacture, technology, and design of small arms and light weapons and their impacts on the implementation of the ITI (UNGA, 2014a).

This chapter supports discussions among UN member states on marking, record-keeping, and tracing. It does so by providing an overview of the key elements related to the development of modular designs for small arms and highlights the challenges that such designs pose to the effective implementation of the ITI and the Firearms Protocol.

Understanding the concept of modularity

Distinguishing parts from accessories

The concept of modularity, as applied to small arms design, is relatively complex. Beyond a limited community of firearms experts, the term ‘modular weapon’ is often erroneously associated with an image of a rifle surrounded by a multitude of accessories that enhance its performance or alter its appearance.³ In fact, modular weapons are quite different. To fully understand the difference, it is necessary first to distinguish clearly between ‘accessory’ and ‘part’ (or component).

For the purposes of this chapter, **accessory** is defined as ‘an item that physically attaches to the weapon and increases its effectiveness or usefulness but, generally speaking, is not essential for the basic, intended use of the weapon’ (Grzybowski, Marsh, and Schroeder, 2012, p. 245).

A **part**, bundled together as ‘parts and components’, is defined by the Firearms Protocol as follows:

‘Parts and components’ shall mean any element or replacement element specifically designed for a firearm and essential to its operation, including a barrel, frame or receiver, slide or cylinder, bolt or breech block, and any device designed or adapted to diminish the sound caused by firing a firearm (UNGA, 2001, art. 3).

Defining modularity

Drawing on these definitions, a **modular weapon** can be broadly defined as: a weapon with a core section (usually the receiver, or the upper or lower section in the case of split-receiver weapons) around which all or almost all other major parts and components can be switched directly, by the user, to

obtain different configurations according to his or her needs (Persi Paoli, 2012).

Such reconfiguration may include changing key parts and components, such as the barrel or the buttstock, enabling the same weapon to be used for different purposes or in different operational scenarios (e.g. in Close Quarter Battle (CQB) or as a Designated Marksman Rifle (DMR)), as well as changing its calibre.

There are two main approaches to modularity, depending on whether the calibre can be changed on a given weapon. In the case of ‘full modularity’, the same weapon can be used, after changing relevant parts, to fire *more than one calibre* of ammunition. This multi-calibre approach is therefore referred to as the ‘common, or universal, receiver’ approach. A second possibility is the ‘family approach’. In the latter, modularity is partial: the same model of firearm is produced in a family of different calibres. The calibre on a given weapon cannot be changed, but all other parts are modifiable and interchangeable (Jacobs, 2013).

Accordingly, a standard (i.e. non-modular) weapon may accommodate several accessories, but since the fundamental characteristics of the weapon remain unchanged, this poses no difficulty in relation to arms control. On the other hand, with modularity, in addition to accommodating different accessories, the same weapon can change in its fundamental characteristics (including type and calibre), thereby challenging existing marking, record-keeping, and tracing frameworks. (See ‘The implications of modularity for marking, record-keeping, and tracing’ below.)

The origins and development of modular design

The Special Forces Combat Assault Rifle (SCAR) programme

In the late 1990s, largely in conjunction with the emerging notion of the ‘future soldier’, arms industries became interested in developing and allocating resources to a new type of rifle. This concept, referred to differently in different countries, is basically linked to the development of new forms of equipment for infantry soldiers so that they could better adapt to a continuously evolving operational environment.

A key milestone in the development of modular weapons was the launch of the Special Forces Combat Assault Rifle (SCAR) programme by the US Special Operations Command (SOCOM) in January 2004 (SOCOM, 2004). The SCAR programme grew out of the preparation by combat developers⁴ from each of the SOCOM commands of the Joint Operational Requirements Document (JORD), in which they defined a new weapons system to meet their specific needs (Crane, 2008, p. 8).

The SCAR programme had two main goals. The short-term goal was to replace all SOCOM's assault rifles, carbines, sub-carbines, battle rifles, and DMR weapons in service at the time with a family of SCAR weapons: a 'light' version (SCAR-L, 5.56 × 45 mm NATO), and a 'heavy' version (SCAR-H, 7.62 × 51 mm NATO)—with an Enhanced Grenade Launcher Module (EGLM) to be installed on both versions. The long-term and overriding goal was to develop and deploy one common-receiver platform: a modular, open-architecture weapon offering multi-calibre capability (Crane, 2008, p. 6).



Image 1. The SCAR-H (above) and SCAR-L (below).

What makes a modular weapon different: SCAR requirements

The main benefit of a modular weapon over its standard counterpart is that a single weapon can be deployed in multiple scenarios or environments through simple reconfiguration allowing its key features to be altered. The detailed performance specifications for the SCAR rifles published in January 2004 (US SOCOM, 2004, attachments 1 and 2) list three main features of particular relevance for this chapter:

- **Modularity of barrel and calibre:** The SCAR family should be adaptable to three separate barrel lengths for varying mission requirements: standard barrel (to accurately engage targets at up to 500 m), the CQB barrel (to accurately engage targets at up to 200 m), and the Sniper Variant (to accurately engage targets at 800 m and beyond). The barrel change should be accomplished either by upper receiver or barrel change at the troop unit level (minimum requirement) or by the operator (optimal requirement), using the necessary tools, ideally within five minutes (optimal requirement). In addition, the SCAR-H should feature an open architecture to allow modularity of calibre.
- **Parts interchangeability:** A second important requirement is the 100 per cent interchangeability of all parts among weapons of the same model, without hand or machine fitting, with no adverse effects on the functioning, reliability, or accuracy of the weapon.
- **Commonality of SCAR systems:** Weapons that are part of the SCAR family, light and heavy, maximize ergonomic and parts commonality: SCAR-H and SCAR-L are the same weapon except in relation to size and calibre. Parts commonality reaches 82 per cent, with 145 of a total of 175 components being interchangeable between the two models (Jane's Infantry Weapons, 2014, p. 6).

In the light of these three types of requirement, it is possible to build upon the general definition given above (see 'Defining modularity'). A complementary definition of the modular weapon would be: a weapon that allows operators to decide on the optimal configuration for any given operational context (through barrel and calibre changes) and to easily exchange parts

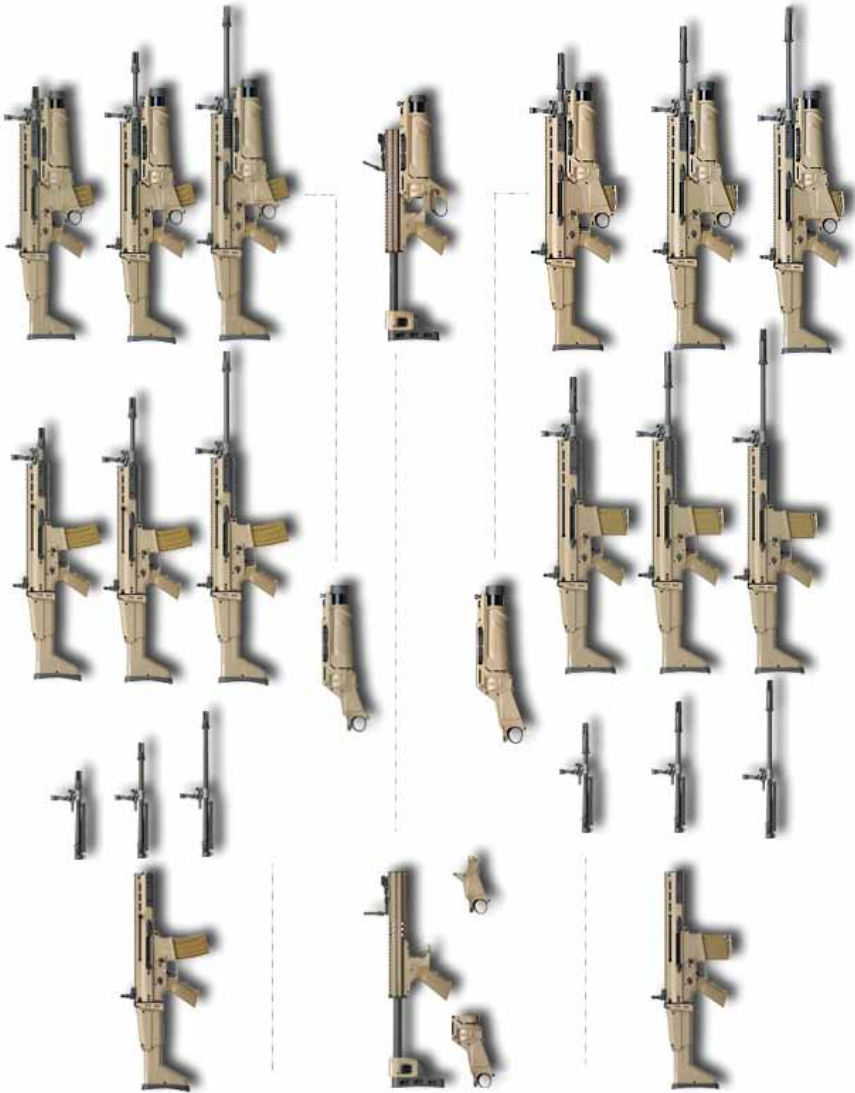


Image 2. The FN SCAR ‘family approach’. Two rifles (in light and heavy variants) featuring an almost complete parts commonality of 82 per cent, with 145 of a total of 175 components being interchangeable between the two models. The two upper receivers can be equipped with different barrels and accessories to obtain different configurations. The heavy variant, SCAR-H (right), features also a common (upper) receiver that would allow the conversion from 7.62x51 to 5.56x45 through the substitution of a limited number of parts.

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and components among weapons when required, owing to the interchangeability and commonality of such parts and components.

Beyond the SCAR: differing approaches to modularity

The ability to change calibre is a key feature of fully modular weapons. There are several approaches to achieving modularity of calibre, each with its own strengths and limitations. These different approaches can be illustrated by three distinct models of modular weapon: the SCAR by FN Herstal, the ARX-160A3 by Beretta, and the CM901 by Colt.

The first variable in the design of a fully modular weapon is its choice of calibre. Each calibre is suited to a different operating environment. For example, 5.56 mm is best suited for medium-range engagements, whereas 7.62 mm can effectively engage targets at greater distances. Although the range of calibres available is increasing rapidly, a few calibres are frequently considered key for military rifles: the NATO 5.56×45 mm and 7.62×51 mm calibres, and the ex-Warsaw Pact 5.45×39 mm and 7.62×39 mm calibres. To this selection can be added the Remington 6.8×43 mm Special Purpose Cartridge (SPC), developed by Remington in collaboration with the US Army to provide increased lethality and better long-range capability than the current 5.56×45 mm NATO calibre (Globalsecurity.org, 2014), while remaining compatible with 5.56 mm rifles.

Producers have chosen different combinations of calibres for their modular weapons. Examples include:

- FN SCAR: the 'heavy' version of the FN SCAR, the SCAR-H is a variant of the SCAR platform optimized to chamber and fire 7.62×51 mm NATO ammunition. A conversion kit is available to switch the weapon to the 5.56×45 NATO calibre. According to open sources, it is also reported to accept standard AK/AKM magazines with Soviet 7.62×39 mm rounds (Military-today.com, n.d.).
- Beretta ARX-160A3: the native calibre of the Beretta ARX-160A3 is the 5.56×45 mm NATO. Via additional conversion kits, the ARX-160A3 can also chamber and fire the Remington 6.8×43 mm SPC and the 7.62×39 mm calibre rounds, fed through AK/AKM-style magazines (Tendas, 2013).

Note that in the case of Beretta, the choice for the 7.62 calibre is not the 7.62 x 51 mm NATO. For this calibre, Beretta is developing a new version of the ARX, the ARX 200, which is chambered in 7.62 x 51 mm NATO with the possibility of conversion to 7.62 x 39 mm (Johnson, 2012).



Image 3. For the ‘heavy’ version of the ARX-160A3, Beretta has chosen the 7.62 x 39 mm against the 7.62 x 51 mm NATO for which a new variant, the ARX 200, is under development.

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- **Colt CM901:** The Colt Modular Carbine CM901 features the two NATO calibres 5.56 x 45 mm and 7.62 x 51 mm (Colt.com, n.d.). At Eurosatory 2014, the land and air-land defence and security exhibition held in Paris, Colt Canada showcased a new variant of the Colt modular weapon system, named CK901. This version is chambered in 7.62 x 39 mm M43 calibre. By late 2014, it had not been possible to confirm whether the CK901 will be convertible to the 5.45 x 39 mm round (All4shooters.com, 2014).



Image 4. The conversion between 7.62 x 51 and 5.56 x 45 includes the quick installation of a magazine adapter.

© Wikipedia

A second key element that distinguishes different types of modular weapons is how the conversion between calibres is achieved. All models of modular weapon feature ‘split-receiver’ architecture: the main body of the weapon, the receiver, is split into a lower part and upper part. Calibre modularity

is achieved by keeping one of the two parts fixed and changing the other. Using the above-mentioned examples, the different approaches are explored:

- FN SCAR: the FN SCAR-H can be converted to fire 5.56×45 mm via a change of the lower receiver. Thus, the upper section is considered the ‘common receiver’.



Image 5. **The SCAR-L partially disassembled.**

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- Beretta ARX-160A3: via a change of magazine and barrel, the Beretta ARX-160A3 can be converted from its original 5.56×45 mm calibre to a 6.8×43 mm SPC version. Similarly to the SCAR-H common (upper) receiver approach, the lower receiver of the ARX can also be changed, along with the barrel and the magazines, to allow the ARX to chamber and fire 7.62×39 mm M43 rounds.



Image 6. **The Beretta ARX-160A3 features a common upper-receiver approach that enables firing 5.56×45 mm and 6.8×43 mm calibres with one lower receiver, and 7.62×39 mm with a second lower receiver.**

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- Colt CM901: another approach to calibre modularity is applied to this weapon. The changeable part is a ‘one-piece monolithic upper receiver’,

available in 7.62x51 mm and 5.56x45 mm versions, which are swapped onto a universal lower receiver. The 'common' receiver is therefore the lower section.



Image 7. As an example of multi-calibre approach, the CM901 features a universal lower receiver that allows calibre modularity via the swapping of the upper receiver monolithic group. This picture illustrates a 7.62 x 51 mm mounted with a 16" (40.6 cm) barrel and the 5.56 x 45 mm upper receiver (with the same 16" barrel) ready for installation.

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The advantages and disadvantages of these approaches depend on various factors, including the number of parts that need to be changed; the size, weight, and cost of the conversion kit; and related operational and tactical considerations. As a general rule, the more parts are compatible with different calibres, the better. The fewer parts that require changing, the quicker the reconfiguration can be completed, with reduced risks of accidentally damaging a part or the weapon itself.

A common upper-receiver approach, such as the one used by the FN SCAR, allows for an easier change of barrel; the user can swap the barrel as an individual part without changing the calibre. Upper receivers are usually fabricated from a type of aluminium, whereas lower receivers can be made of reinforced industrial polymers, making the corresponding conversion kit comparatively light in weight and potentially cheaper.⁵ The disadvantages of this method arise from the fact that barrels and calibres are normally optimized to engage targets at varying distances and settings. In order to maximize accuracy and minimize the risk of unintended death or injury (such as nearby civilians or allied forces), the user should adjust ('zero') the sight or optic according to the calibre and type of barrel. Sights and optics are usually mounted on the upper receiver and, with a common upper-receiver approach,

need to be 're-zeroed' following each conversion. This operation can take precious time and, depending on the circumstances, may not be possible.

The alternative to the common upper receiver is the universal lower receiver used by Colt in its CM901. In this case, the barrel and the upper receiver are a single, monolithic block, available in both 5.56 mm and 7.62 mm calibres. To convert to different calibres or barrels, the user swaps the upper-receiver block with all the optics already attached to it and adjusted to the specific calibre or barrel length. This is the key benefit of a universal lower-receiver approach: the 'swap and fire' concept that comes at the expense of physically bigger—and potentially heavier—parts to be carried and potentially higher costs.



Image 8. **Modular weapons offer a wide range of calibre and barrel-length combinations. In the case of the CM901, these combinations are all achieved through swapping the upper receiver on the universal lower receiver. Each upper receiver block can have its own sight/scope mounted, already 'zeroed', ready to be installed.**

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The extent to which modular weapons will be used to their full potential in practice will depend on such things as the development of new types of ammunition—for example with polymer cases or entirely without cases—and of lighter magazines to reduce the weight of ammunition that soldiers carry. The weight factor is critical: having a weapon fit to fire three different calibres would not necessarily result in a soldier carrying the magazines and ammunition for all calibres simultaneously. The choice of calibre would usually be made before the mission begins, with each operator preparing his or

her rifle configuration according to the assigned tasks. Depending on the type and duration of the mission, a soldier might choose a primary calibre for both the weapon and (ready to hand) 'first and second line gear', keeping the calibre conversion kit with related ammunition in a 'third line' (for example, a backpack).⁶

Modular versus standard design: a cost perspective

While the preceding section summarizes the main physical features of modularity, the differences between a standard and a modular weapon also have an economic dimension. A modular weapon may cost up to 30 per cent more than a standard weapon of the same type and calibre,⁷ but this difference in cost is only one consideration. For example, a contingent of 1,000 soldiers equipped with 5.56×45 mm, 7.62×51 mm, and 7.62×39 mm calibre rifles would usually call for 1,000 standard rifles of each calibre (3,000 rifles in total), plus related spare parts. Yet 1,000 modular rifles plus two conversion kits per rifle would provide the same range of calibres as 3,000 standard rifles. Although the unit cost of modular weapons tends to be more expensive than standard models, they offer significant savings at the broader troop level. For example, the SCAR programme was designed to replace five different rifles, first with a family of two modular rifles in different calibres and subsequently with one common-receiver rifle capable of five different configurations of calibre and barrel (Crane, 2008).

Despite these apparent benefits in pricing, complex political and economic considerations have to date prevented modular weapons from replacing standard ones. From a political perspective, only a limited number of manufacturers produce modular rifles and many governments prefer to buy from their national defence industry. The second obstacle arises from inherent conservatism and doubts regarding the reliability of the (relatively) recently developed modular weapons. In comparison to standard rifles, which have already been used in a wide variety of different settings and climatic conditions, modular weapons have undergone only limited field-testing. Given the typically conservative nature of the military small arms market, the relatively recent development of fully modular weapons could influence procurement decisions.

A further factor is related to the lifespan of rifles currently in service. Budgetary constraints may dictate that governments resort to replacing a weapon (or a stock thereof) only when it is approaching the end of its life cycle. Such a decision is based on the age of the weapon, the extent of use, and availability of spare parts. Should the three types of standard rifle in the example above reach the end of their life cycle simultaneously, selecting a modular weapon to replace them all would be of unquestionable economic and operational benefit.

In reality, in order to minimize their initial investment, most governments are likely to launch replacement programmes for one rifle type at a time, a strategy that disadvantages modular weapons, which have a higher unit price. Nevertheless, all producers of modular weapons should allow customers to order their conversion kits after having purchased the weapon. Governments that are prepared to make a higher initial investment, replacing a standard rifle with a modular design, could offset this price difference at a later stage when replacing another standard rifle of a different calibre. Instead of buying a new stock of rifles, they would simply need to order conversion kits for the modular weapons already in service.

The advance of modular weapons in the military arms market will be more evident after the rifle-replacement programmes currently underway: France is replacing the FAMAS (Wilk, 2014); India is replacing the INSAS rifle (Thefirearmblog.com, 2014); and New Zealand is replacing its inventory of Steyr AUG rifles (Tomkins, 2014). As of November 2014, it appeared likely that at least one type of modular weapon would feature in each of these replacement programmes (Wilk, 2014; Thefirearmblog.com, 2014; Tomkins, 2014). The degree of success of modular weapons in this context should set the tone for their future role.

The significant reduction in the number of different weapons used results in three key sources of economic savings, in addition to the lower acquisition costs described above. First, logistics costs should be significantly reduced. Every weapons system has its own unique logistical requirements, including supply-chain management for spare parts, service (including repair and maintenance), tools, and manuals. The more weapons there are in service, the greater the logistical effort, and the higher the costs. By reducing the

total number of arms deployed, modular weapons improve the ‘logistical footprint’ of a combat unit (Crane, 2008, p. 20).

Second, there are savings in training costs. Each weapon requires specific training to allow the operator to become familiar and confident in its use: the so-called ‘muscle memory’. Once again, the greater the number of weapons in service, the more training an operator requires. With modular weapons, training is optimized. With the SCAR family, for example, in both light and heavy variants, their ergonomics and adjustments (e.g. sight-calibration for different ranges) are the same and their dimensions and weight very similar. An operator trained to use one rifle is effectively trained to use the others. Taking into account barrel modularity, which allows operators to switch among up to three different barrel lengths, combined with two possible choices of calibre, an operator trained for one weapon would, in effect, be trained for six—or 12, with the inclusion of the grenade launcher on all possible configurations (Crane, 2008, p. 6).

Finally, there are economies of scale when a modular weapon is the weapon of choice, not only for units of limited size (e.g. Special Forces), but also for an entire army or police department. At the army level, stocks consisting of tens, or potentially hundreds or thousands of weapons (of different models and from different producers) could be replaced by a significantly lower total number of weapons—all of one model, reconfigurable according to need.

The three benefits described above apply to all approaches to designing modular weapons: family, common upper receiver, and universal lower receiver. The benefits are, however, more pronounced with the latter two as calibre modularity enables one rifle to be deployed in several different configurations and calibres.

The implications of modularity for marking, record-keeping, and tracing

The features which make modular weapons appealing to many users—barrel and calibre modularity, parts interchangeability, and commonality—pose key challenges for marking, record-keeping and, consequently, tracing. While the concept of modularity has taken firmer root in the past ten years, its implications for arms control have been largely overlooked. To fully

understand such challenges, it is important to switch from the traditional notion of a rifle to a more complex one: a weapon system made of several different parts and components, which can be combined in different ways to obtain a desired configuration.

Challenges for marking

The marking provisions inherent to the ITI and the Firearms Protocol do not adequately address the challenges posed by modularity.

Marking location

The Firearms Protocol requires states parties to mark ‘each firearm’, without specifying which part or component to mark (UNGA, 2001, art. 8). The ITI provides more guidance on this, recommending that UN member states apply the mark ‘to an essential or structural component of the weapon where the component’s destruction would render the weapon permanently inoperable and incapable of reactivation, such as the frame and/or receiver’ (UNGA, 2005, para. 10).

Even before the advent of modular weapons, there were different interpretations and practices regarding which component was deemed ‘essential or structural’. With modular weapons, it is critical to identify a ‘control component’ for marking in order to avoid subsequent confusion and misinterpretation of weapons marks.

For modular firearms, the control component would logically be the receiver, upper or lower—depending on the approach used by the producer to achieve calibre modularity—as any other part is interchangeable.

Duplication of marks

The application of marks to more than one part of a firearm is a widespread practice, encouraged also by the ITI:

States are encouraged, where appropriate to the type of weapon, also to apply the marking prescribed in subparagraph 8 (a) above or other markings to other parts of the weapon such as the barrel and/or slide or cylinder of the weapon, in order to aid in the accurate identification of these parts or of a given weapon (UNGA, 2005, para. 10).

Given the high interchangeability and commonality of parts and components that characterize modular weapons, the application of marks to more than the ‘control component’ could lead to confusion and error in the identification of the weapon. For example, assuming that the serial number was marked on both the upper and lower receiver, as well as the barrel, a modular weapon would present three different serial numbers, one for each part, once the lower receiver and barrel were changed.

Marking content

The ITI specifies the information that is to be marked on each small arm or light weapon at the time of manufacture. Mandatory information includes, for most countries, the name of the manufacturer, country of manufacture, and serial number. States are also encouraged to mark additional information, such as the weapon’s type, model, and calibre (UNGA, 2005, para. 8(a)).

The rationale is to have as much information as possible to support the unique identification of a firearm. In the case of modular weapons, however, this unique identification may no longer be achievable, or at least not in the same way, as barrel and calibre modularity allow an operator to reconfigure the weapon into different ‘types’ and calibres. Markings for modular weapons should therefore either list all possible types and calibres or mention only the serial number and model. Any other approach could result in misinterpretation and error.

Challenges to record-keeping

All challenges regarding marking generate related issues for record-keeping. The ITI does not provide specifically for the keeping of records relating to weapons parts and components, instead referring generically to ‘all marked small arms and light weapons’ (UNGA, 2005, para. 11). The Firearms Protocol is somewhat more comprehensive, in that its record-keeping provision refers to ‘information in relation to firearms and, where appropriate and feasible, their parts and components’ (UNGA, 2001, art. 7).

Two main implications for record-keeping stem from the increased use of modular weapons:

Creating a record

An initial challenge arises with the creation of a record for a modular weapon. In particular, it is necessary to identify a ‘reference’ part—or ‘control component’—on which marks can be used to create a record associated with that weapon, whatever changes of configuration it undergoes. As indicated above, the core component of a modular weapon, as with a normal rifle, is either the upper or the lower section of the receiver, depending on which section remains unchanged among all possible configurations. Only marks applied to the relevant receiver section should be used to create and manage records, as all other components of a modular weapon are easily interchangeable.

Accounting for configurations

Second, it is necessary to determine whether and how to account for the different configurations of a modular weapon. Considerations include: How should the different combinations of calibre and barrel length be reflected in the records? Should each configuration have its own separate record indicating its specific characteristics? Or, perhaps more practically, should there be only one general record associated with the serial number on the relevant section of the receiver (either upper or lower), possibly with a list of all of the possible configurations for that weapon? Given the interchangeability and commonality of parts in a modular weapon, it is not possible to permanently link one receiver with a specific set of parts and components. This affects the potential traceability of the weapon (see ‘Challenges to effective tracing’).

Challenges to effective tracing

Marking and record-keeping are prerequisites to successful tracing, and with modular weapons, the distinction between a rifle and its components is no longer clear. This poses particular challenges to effective tracing, particularly related to identification. A necessary, but insufficient, condition of successful tracing is the correct identification of the firearm to be traced. With modular weapons, the first question is which part should be considered the main reference for identification when different serial numbers (or other markings) are applied to different parts. The need to identify a control


component of the weapon is therefore fundamental for the tracing of modular weapons. A second issue relates to the amorphous nature of type and calibre in modular weapons. The marks on the receiver might be very general and exclude data on type and calibre, or they might be very specific and include such information, but possibly not correspond to the configuration in which the weapon is found.

Conclusion

Recent industrial developments and rifle-replacement or procurement programmes in several countries around the world (see Wilk, 2014; Thefirearmblog.com, 2014; Tomkins, 2014) suggest that modular weapons, reflecting several different approaches to multi-calibre capability, will become increasingly prominent in national inventories. Modular design poses numerous challenges to arms control, in particular regarding the marking, record-keeping, and tracing of firearms.

Addressing these challenges will require the revision or amendment of applicable international instruments so that they:

- identify a control component for all firearms, normally the frame or receiver, whether standard or modular, for marking, record-keeping, and tracing purposes. For modular weapons featuring a split receiver, the control component would presumably be the section—whether upper or lower—that remains unchanged among all possible configurations;
- determine what information should be marked on the control component and on other components to avoid the duplication of serial numbers and minimize the risk of inconsistency between a modular weapon’s configuration at a particular time and the information marked;
- acknowledge the intrinsic difference between standard and modular firearms and encourage the optimization of record-keeping practices by moving from a ‘firearm focus’ to a ‘control component focus’; this could include guidance on how different configurations of modular weapons should be accounted for in national records; and
- provide guidance on unique identification for tracing purposes, in particular with respect to modular weapons.

UN member states will have an important opportunity to consider such questions at the 2015 Open-ended Meeting of Governmental Experts (see UNGA, 2014b, para. 40). 

Endnotes

- 1 Full name: International Instrument to Enable States to Identify and Trace, in a Timely and Reliable Manner, Illicit Small Arms and Light Weapons (‘International Tracing Instrument’). See UNGA (2005).
- 2 Full name: Protocol against the Illicit Manufacturing of and Trafficking in Firearms, Their Parts and Components and Ammunition, supplementing the United Nations Convention against Transnational Organized Crime. See UNGA (2001).
- 3 The concept of enhancing the performance of weapons by adding a set of standardized accessories was introduced in the early 1990s by the United States, with the launch of the Special Operations Peculiar Modification (SOPMOD) Accessory Kit Program. See Globalsecurity.org (2011).
- 4 In its Glossary of Defense Acquisition, the Defense Acquisition University defines this as ‘[C]ommand or agency that formulates doctrine, concepts, organization, materiel requirements, and objectives. May be used generically to represent the user community role in the materiel acquisition process’ (Hogan, 2012).
- 5 The actual price of the conversion kits is not published. The author’s consultations with representatives of the armed forces suggest that a conversion kit for an upper common receiver might be cheaper than the conversion kit for a universal lower receiver.
- 6 Author’s private consultations with representatives of the Italian Army.
- 7 Author’s private consultations with representatives of the arms industry.

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III. Small arms and additive manufacturing: An assessment of 3D-printed firearms, components, and accessories

N.R. Jenzen-Jones

Introduction

As 3D printers that use additive manufacturing (AM) processes become increasingly available worldwide, so too do 3D-printed firearms, components, and accessories. Technologies such as fused deposition modelling (FDM) and direct metal laser sintering (DMLS) have been used to manufacture weapons that have been widely claimed as functional (McGowan, 2013; Greenberg, 2013a). 3D printing presents numerous advantages for the firearms manufacturing industry, including saving on materials in manufacturing; rapid design and prototyping; swift transfer of designs globally; high levels of customization; and more efficient manufacture of complex products (Overton, 2013).

Understandably, the advent of a new technology in the arms manufacturing industry has caused various stakeholders some consternation. Law-enforcement agencies, policy-makers, manufacturers, and users each have their own concerns regarding the implications of the technology. Some of the advantages of 3D-printing processes may also pose concerns for the development and application of national legislation and international instruments. Governments may seek to examine their national legislation in light of the advent of 3D-printed weapons, components, and accessories, and will require a thorough understanding of the technical and legal issues at hand in order to do so.

Most stakeholders seem to be concerned mainly that individuals or small groups may be able to produce completely untraceable firearms without government oversight. Moreover, the manufacture of components and

accessories may allow for firearms to be modified or converted for purposes other than their original or licensed capabilities.

To date, no thorough technical assessment of the application of AM technology to the production of small arms—or of specific 3D-printed firearms, components, and accessories—has been made public. This chapter offers researchers, policy-makers, and other stakeholders an impartial examination of the current state of 3D-printing technology as it relates to the manufacture of firearms, components, and accessories, and a technical assessment of a select number of them. The chapter also considers the likely future trajectory of additive manufacturing.

The chapter has benefited from the assistance of experts in firearms and additive manufacturing, designers of 3D-printed firearms and firearms components, and qualified armourers. It also draws on interviews with specialists and industry professionals, as well as on reporting in the mainstream and new media.

The topic of 3D-printed firearms has become politically charged in many respects, and sensationalized by the media and other observers. This chapter, which focuses on the technical merits of AM processes and outputs for the firearms industry, offers an impartial contribution to the ongoing discussion.

Additive manufacturing today

The additive manufacturing industry

Private and government-sponsored researchers developed 3D-printing technology in the 1980s. Early pioneers such as Chuck Hull, inventor of stereolithography (SLA) and the stereolithography file format (STL), founded the first private companies in the AM sector (3D Systems, Inc., n.d.; Hickey, 2014). Other groups, such as a research team at the University of Texas at Austin in the United States, led by Carl Deckard and Joe Beaman, inventors of selective laser sintering (SLS), received government funding (Grosvenor and Lou, 2012).

Until recently, 3D printing was limited to low-volume industrial manufacturing (most commonly for rapid prototyping) because of financial and

technological considerations. In addition, highly protected patents served as effective barriers to entry. Over the past five years, however, a number of expiring patents and the rapidly decreasing costs of low-end 3D printers have led to a boom in the AM sector, and have facilitated the significant involvement of hobbyists and entrepreneurs (Wadhwa, 2013).

Further growth is widely expected, with another series of important patents having expired in late 2014 (Hornick and Roland, 2013). Wohlers Associates, market analysts specializing in the AM industry, predict significant growth, expecting the global AM industry to reach USD 4 billion in 2015 and USD 10.8 billion by 2021 (McCue, 2013). While most industry consultants estimate that the 3D-printing market will grow by approximately 20 per cent annually, Credit Suisse suggested that industry growth is more likely to be between 20 and 30 per cent (Wile, 2013a). Goldman Sachs has referred to 3D printing as a 'creative destroyer' and suggested that it will command greater attention in the coming years (Wile, 2013b).

Critics, who point to the failure of the market to mature over the past 30 years and the poor performance of stocks in major AM companies, are sceptical about revolutionary growth. Several observers suggest that 3D printing is likely to remain restricted to rapid prototyping and advanced, high-cost manufacture (BloombergTV; 2014a; 2014b). Designing for 3D printing remains difficult and although high-end printers can produce high-quality products from metals and advanced polymers, such printers remain prohibitively expensive for hobbyists and small businesses (Baartz, 2014). Where necessary, many firms outsource 3D-printed design and manufacture to larger companies in the industry.

Additive manufacturing and the firearms industry

Anecdotal evidence suggests that a small number of firearms manufacturers used 3D printing for rapid prototyping as early as the mid-1990s and that these companies made use of SLA and SLS to develop prototype components, primarily for mock-up weapons used to test ergonomics.¹ At least one of these companies outsourced this printing to a large 3D-printing company. Magpul Industries Corporation is believed to have used in-house 3D

printing for prototyping its Masada assault rifle² and FMG-9 folding sub-machine gun.³ Many firearms companies continue to use 3D printing, often outsourcing this to companies such as Solid Concepts, LLC, based in Austin, Texas in the United States. Solid Concepts is the only AM contract manufacturer to hold a US Federal Firearms License (FFL), allowing it legally to manufacture firearms and silencers in the United States (Parkinson, 2013b).

3D-printed firearms gained widespread media attention in 2013 when Cody Wilson of Defense Distributed announced plans to build a fully printable polymer weapon. In May that year, he demonstrated and fired the single-shot, polymer Liberator (Defense Distributed, 2013a; McGowan, 2013). Defense Distributed claims to have produced an improved version of an AR-15 lower receiver, and to have successfully fired 600 rounds of .223 ammunition, thanks to Michael Guslik's reinforced design (Defense Distributed, 2013b).

3D-printed firearms and components that are manufactured from metals remain very rare. In November 2013, Solid Concepts released its 1911 DMLS (named after direct metal laser sintering, the process used in the weapon's manufacture), demonstrating that it is possible to produce a fully printed functional metal firearm, albeit very expensively (McGowan, 2013). Complete firearms produced by using DMLS are not yet commercially viable, but the process is used to produce a handful of 3D-printed components and accessories, including Sintercore LLC's 3DX⁴ muzzle brake (Sintercore, n.d.) and the upper receiver for the LOSOK Arms Mk 36 rifle (Soldier Systems, 2014).

Amateur 3D-printed firearms

The open source community has been quick to adopt the design and manufacture of polymer 3D-printed firearms and components, as polymers are significantly cheaper and more readily accessible to hobbyists, craft producers, and small businesses. Computer-aided design (CAD) files for various firearms and components have been available since the early 2000s (Guslik, 2012; Snider, 2003). As expiring patents and technological developments are leading to more affordable 3D printers, amateur-built 3D-printed firearms are increasingly common.

One of the earliest firearm components produced was an AR-15 upper and lower receiver, developed in September 2011 (M4carbine.net, 2011). Michael

Guslik developed a handgun chambered for .22 LR, built on a 3D-printed AR-15 receiver, which was successfully test-fired and refined (Guslik, 2012). Since then Guslik has also produced a 3D-printed Ruger 10/22 receiver (Guslik, 2013).

There has been considerable media attention paid to the proliferation of amateur-grade additively manufactured firearms in jurisdictions outside the United States, especially where firearms are heavily controlled. Shortly after Defense Distributed released the CAD files for its Liberator firearm, two journalists successfully printed and smuggled an example on to a train running between the UK and France (Worstell, 2013). Journalists in Israel defeated some of the country's toughest security screenings, smuggling a 3D-printed firearm into the Knesset on two occasions (*Haaretz*, 2013).⁵ A Japanese man recently became the first known person to have been arrested for printing a firearm; he maintained that he did not realize it was illegal to do so (Coldewey, 2014).

Current additive manufacturing technologies

Stereolithography (SLA)

Stereolithography (SLA), sometimes referred to as optical fabrication, uses an ultraviolet (UV) laser or similar power source to cure photo-reactive resins layer by layer. SLA printing generally produces models with a high level of detail. The strength of the product means that it can often be machined or used as a master for injection moulding and metal casting (Savla Associates, n.d.). The drawback of this method tends to be expense, as resin often costs more than USD 100 per litre. Industrial SLA printers can cost hundreds of thousands of dollars, although much smaller consumer versions can be purchased from around USD 2,800 (Formlabs, n.d.). Several firearms companies have used SLA process printers to produce 3D-printed mock-ups of weapons and components, and some appear to have done so from the mid-1990s. According to industry sources, several companies continue to make use of SLA printers, predominantly for rapid prototyping.⁶

Fused deposition modelling (FDM)

Also known as fused filament fabrication (FFF), FDM is the most recognizable form of 3D printing. FDM printers extrude thin filaments of thermoplastic material through a heated nozzle to construct a three-dimensional object. They are capable of producing accurate results, with layers that typically range between 75 and 300 microns in thickness (Thre3d, n.d.b). Commonly seen in both commercial and consumer use, FDM printers are relatively inexpensive, and may be fed using a wide range of thermoplastic and organic material blends, including ABS (acrylonitrile butadiene styrene), PLA (polylactic acid), and polycarbonate. Consumer-grade machines typically cost thousands of dollars (although there are several examples now costing less than USD 1,000), whereas commercial examples cost thousands to tens of thousands of dollars. Although products are typically limited to light-duty applications, professional printers are capable of forming advanced thermoplastics that have demonstrated fire-retardant properties. One of the leaders in FDM printers, and a driving force behind the production of consumer-grade 3D printers, is Stratasys, the manufacturer of the uPrint SE printer used by Defense Distributed to print the Liberator handgun (Beckhusen, 2012).

Direct metal laser sintering (DMLS), selective laser melting (SLM), and selective laser sintering (SLS)

Direct metal laser sintering (DMLS), selective laser melting (SLM), and selective laser sintering (SLS) are industrial processes capable of producing highly accurate models with excellent mechanical properties. All three systems stipulate that powder be laid down in layers 20–60 microns thick within a tightly sealed chamber typically filled with inert gas, with a high-powered fibre optic laser fusing the powder at specific points (Thompson, 2013). As the excess powder is typically reusable, these processes involve much less waste than traditional (i.e. subtractive) manufacturing processes.

Typical metal alloys used include stainless steel, maraging steel, cobalt, chromium, Inconel, and titanium, but in theory almost any alloy or pure metal can be used once it has been fully developed and validated (Thre3d, n.d.a). Many 3D-printed metal-alloy components have mechanical properties

similar or superior to those produced using traditional manufacturing techniques (EOS, 2007). Typical polymers used in SLM and SLS include both filled and unfilled nylons and high-temperature, chemical-resistant polymers such as polyether ether ketone, known as PEEK (Solid Concepts Inc., n.d.).

The significant technology gap between DMLS, SLM, SLS, and other processes such as FDM is reflected in the price of the equipment; DMLS printers can cost anything from USD 600,000 to USD 1 million. As a result, specialist 3D-printing companies that have access to DMLS and similar machinery, such as Solid Concepts Inc., have been approached by various larger firearms companies to produce 3D-printed parts—for both prototyping and production parts.⁷ Solid Concepts' 1911 DMLS pistol was produced on an EOSINT M270 printer (see Image 1), as are many components it produces on contract for other firearms manufacturers. DMLS, SLM, and SLS are of interest to the aerospace, automotive, and medical industries, but are not currently commercially viable for the production of many firearms components. One of the primary limitations is part size, since many machines are equipped with a build envelope that is no greater than approximately 250 x 250 x 320 mm (Thompson, 2013).

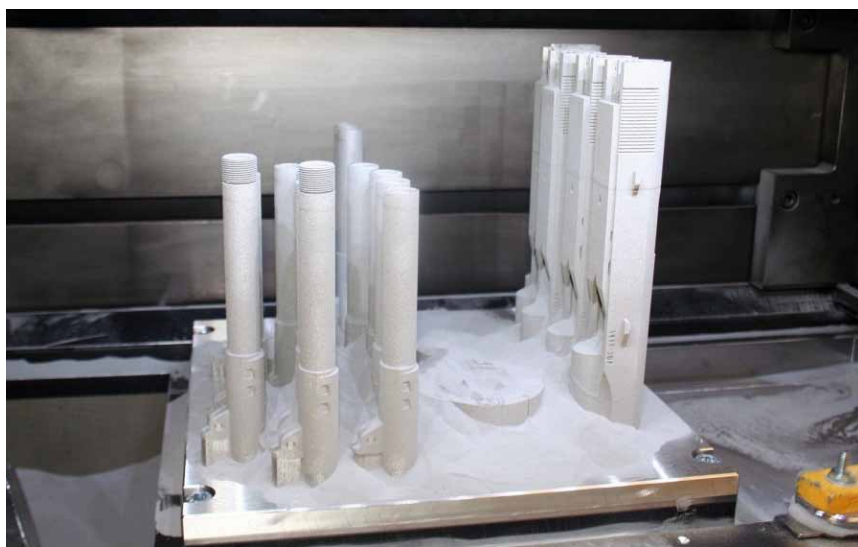


Image 1. Components (barrel and slide assemblies) of a Solid Concepts 1911 DMLS pistol, produced using DMLS.

© Solid Concepts, Inc.

Other technologies

There exist other, less common AM processes, such as binder jet printing (BJP), electron beam freeform fabrication (EBF), and electron beam melting (EBM). BJP differs from other processes by using alternating passes of a liquid binding material, followed by a powder, in order to form each cross-sectional layer of the object being printed. EBF uses a focused electron beam in a vacuum to create a molten pool of the desired metal alloy on a metallic substrate, with the material solidifying immediately after the beam passes. EBM differs from SLM only in the use of an electron as opposed to a laser beam to melt metallic powder layer by layer in a vacuum environment (Smallwood, 2014).

Assessment of current 3D-printed firearms

Defense Distributed Liberator

The first viable firearm produced using a 3D printer appeared in early 2013. The ‘Liberator’ handgun is entirely plastic—except for a metal firing pin, typically a nail (see Image 2). It is a turn-off barrel, single-action, single-shot .380 Automatic Colt Pistol (ACP) calibre handgun designed by ‘HaveBlue’ of the DefCAD forums (DefCAD, n.d.) and named after a conceptually similar progenitor dating from the Second World War. Importantly, early iterations of the weapon did not have a rifled barrel, which would greatly diminish its accuracy. Later derivatives such as the ‘Lulz Liberator’ use a rifled barrel (Greenberg, 2013c), although it is not known how effective this rifling is.⁸ The DefCAD design requires a block of metal to be embedded in the frame of the weapon, in compliance with the US Undetectable Firearms Act of 1988, but in practice this can easily be omitted during assembly. The first working example was printed, finished, and tested by Defense Distributed, and received a great deal of attention from the media and law-enforcement agencies worldwide (Greenberg, 2013d; PJ Media, 2013). Wilson and others in the DefCAD and 3D-printing community were able to produce examples that successfully fired between one and 11 shots before structural failure. The Liberator was originally printed on a Stratasys uPrint SE FDM printer using ABS plastic (Greenberg, 2013d).

Testing conducted by the New South Wales Police in Australia confirmed that the Liberator could successfully fire a .380 ACP cartridge and was indeed a potentially lethal firearm (New South Wales Police, 2013). This and a similar test conducted by the US Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) also concluded that manufacturing the firearm from plastics other than the ABS specified could lead to a catastrophic failure and potentially injure the user (ATF, 2013a). The New South Wales Police test firing resulted in a penetration of some 17 cm into 10 per cent ordnance gelatine, typically considered a marginally lethal result. This example also suffered a catastrophic failure on firing, which would have reduced the muzzle velocity of the projectile. How viable a given example might be depends upon a wide range of variables, including printer hardware and software, calibration of the printer, the material used, and whether the resulting components are correctly finished and assembled.

Like many hobbyist projects, more work is required than simply clicking 'print'. Even under optimal conditions, the barrel of the weapon must be twisted off and the fired case pushed out with a stick prior to reloading (or a spare, pre-loaded barrel used). Unlike most other expedient firearms, the Liberator requires no engineering skills or machine tools, but does call for IT skills and an understanding of 3D printing. Through application, online collaboration, and some trial and error, a potentially lethal firearm can be produced. Improved designs are under development, and materials will no doubt improve over time (Ferguson, 2014; Slowik, 2013).



Image 2. **The Defense Distrusted Liberator pistol, disassembled to show its component parts. Note the metal firing pin (nail) visible.**

© Michael Thad Carter/Forbes

without replacement of parts, and has already sold examples to the public for USD 11,900 each (Parkinson, 2013). Again, the technologies and materials involved can only improve. In terms of functionality, the Solid Concepts 1911 closely mirrors commercially available 1911-type pistols in all respects and, unlike the standard Liberator, features a 7-round capacity and a rifled barrel. It remains to be seen whether laser sintering is likely to 'trickle down' from the world of industrial prototyping and specialist component manufacture to the domestic market, as FDM and SLA have done.

3D-printed firearms components and accessories

Some of the earliest firearms components to be produced using AM processes were lower receivers for AR-15 type rifles. These continue to be produced by several manufacturers, especially in the United States. Versions of so-called '80% lowers', which are finished by the final user, do not constitute firearms receivers under US law, i.e. under the Gun Control Act of 1968 (US, 1968), and hence are not subject to registration.⁹ To date, all commercially available unfinished lower receivers produced using AM processes have been manufactured from polymers.

Some commercially available firearms will soon be released featuring 3D-printed components. For example, a rifle being developed by Ohio Ordnance Works, the HCAR, reportedly uses SLS for at least some of its furniture (Soldier Systems, 2013).¹⁰ As previously mentioned, the LOSOK Arms Mk 36 features an upper receiver (produced by Solid Concepts), which is manufactured using DMLS, and a 9 mm sub-machine gun is reportedly being developed for the Taiwanese military featuring a 3D-printed folding buttstock (Johnson, 2014).¹¹

The process of copying and printing firearms components in polymer is more complex and challenging than is often assumed. If the part is to play even a minor mechanical role in the operation of the weapon, a significant amount of re-engineering is typically required before it can be integrated into the firearm. Most components and accessories that are produced in polymer using additive manufacturing are non-structural, such as pistol grips and buttstocks. While some structural components have been produced, such as lower receivers for AR-15 type weapons, these are largely not

pressure-bearing components. In the AR-15 design, for example, the thermal and mechanical stresses of firing are borne mainly by the barrel, bolt, and upper-receiver assemblies. The lower receiver is primarily intended to ensure the correct alignment and interface of the operating parts of the firearm, and to house the trigger and fire selector and safety mechanisms.

For quite some time prior to the production of 3D-printed polymer versions, AR-15 lower receivers had been machined from aluminium (a low-strength metal). Nonetheless, an AR-15 lower receiver does have certain structural strength requirements; the recoil buffer is housed in the lower receiver, which exerts some strain on this component when fired. Producing a copy of a firearms component in a material of lower strength than the original material used can lead to structural failures.

One of Defense Distributed's detailed reports on the testing of a 3D-printed polymer AR-15 lower receiver shows that it failed after firing just six rounds of 5.7 x 28 mm ammunition; a cartridge producing much lower recoil than the 5.56 x 45 mm or .223 Remington ammunition for which AR-15 type weapons are most commonly chambered (Defense Distributed, 2013d). Rather than producing a direct copy of the traditionally machined part, designers must re-engineer the component so that, using their chosen polymer, it can perform the same functions as the traditional part. Defense Distributed has since modified the AR-15 lower-receiver design and has successfully test-fired over 600 rounds of .223 ammunition (Defense Distributed, 2013b).

Aftermarket firearms accessories are also beginning to be produced using AM techniques. Sintercore LLC produces a 3D-printed muzzle brake, which is manufactured using DMLS. The 3DX muzzle brake has received generally favourable reviews, and is of a comparable price to other premium muzzle brakes on the market (Sintercore LLC, n.d.). The 3DX is produced from Inconel alloy, and is machined after printing to finish the threading. According to Sintercore, some of the design features of its muzzle brake could not be produced using traditional machining, casting, or electrical discharge machining (EDM) manufacturing techniques.¹²

The Te-Titan sound suppressor, developed and produced by the Norwegian company Tronrud Engineering, benefits from AM techniques since it is produced as a single piece, made entirely from Ti64 titanium alloy (see

Image 4).¹³ The suppressors are extremely tough, and can be used in conjunction with rifles chambered for a wide range of standard calibres. They are commercially available in Norway, and purchased by hunters, competition shooters, and law-enforcement agencies. There have been reports of hunters using the Te-Titan on large, magnum calibre rifles without experiencing any safety issues. The Te-Titan is comparably priced with other premium suppressors for larger calibre rifles, with a retail price of around EUR 675 in Norway.¹⁴ Oceania Defence also manufactures a series of titanium suppressors using DMLS, which the company describes as the least expensive on the global market (Oceania Defence, n.d.).

Several design files are now available that allow for the 3D printing of magazines for various firearms. In 2013, Defense Distributed tested the 'Cuomo' 30-round magazine for the AR-15 and, based on variants printed in both an SLA epoxy resin and ABS plastic, claimed that the magazine would work for 'well past 100 rounds' (Defense Distributed, 2013c).



Image 4. **The Tronrud Engineering Te-Titan suppressor.**

© Tronrud Engineering

The future of additive manufacturing technology in the firearms industry

Aerospace and defence accounted for 10.2 per cent of the AM industry in 2012, and analysts expect this market share to increase (Coykendall et al., 2014). High-end manufacturing, particularly SLS and DMLS, will remain too costly for individuals and most groups for the next decade or so. Other manufacturing options are likely to remain more viable. For example, high-end FDM and SLA 3D printers will probably become more affordable for individuals and groups over the next five to ten years. At the same time, traditional

manufacturing is also advancing and high-end computer numerical control (CNC) machines are likely to become less expensive in the coming years. An AR-15 bolt can be produced in approximately nine minutes on some of the most recent CNC machines, such as the SwissTech AB 42 (WeaponsMan, 2014). High-end 3D-printing systems are likely to remain relatively easy for law-enforcement and intelligence agencies to monitor and so are unlikely to be attractive for groups wishing to remain undetected.

As the 3D-printing industry expands, a number of trends are likely to make it more accessible to consumers:

- significant projected investment is likely to increase economies of scale and reduce the costs of printers and materials;
- printers are likely to become easier to use, and CAD files and software are likely to become more readily available; and
- significant patents have expired, and are likely to provide a notable boost to the amateur industry, particularly in terms of available materials (Hornick and Roland, 2013).

The availability of more advanced materials, as well as the introduction of new manufacturing techniques, or new combinations of existing manufacturing techniques, are likely to advance the capabilities of 3D printing at both the consumer and commercial levels. Existing ABS plastics can be used for the construction of certain firearm receivers and housings, but since they cannot endure the heat and pressure produced by the operation of a firearm, they are unsuitable for essential components such as the barrel, gas system, and bolt (Ferguson, 2014).

The use of modern, advanced polymers may offset some of these limitations. One such polymer, polyether ether ketone (PEEK), is a semi-crystalline thermoplastic with a high resistance to temperature and mechanical wear. Although they are more expensive than typical plastics, advanced polymers are still significantly cheaper to print than any currently available metals. One specialist in 3D printing claims that polymers such as PEEK could be used to craft the 'skeleton' of critical parts, and, when used in conjunction with post-processing technologies such as electroless nickel (EN) undercoating and carbon and titanium-based physical vapour deposition (PVD) top

coating, could produce a relatively inexpensive, lightweight, and mechanically superior plastic–metal hybrid component.¹⁵ Such configurations may be viable for more critical parts, such as upper receivers, or other parts subject to mechanical, thermal, or chemical stresses that normal polymers could not typically withstand. 3D-printed production parts manufactured from PEEK using SLS are currently being used in the F-35 Joint Strike Fighter (Paramount Industries, Inc., n.d.).

Additive manufacturing is also a comparatively low-cost manufacturing method for working with materials that are very hard, and therefore expensive and time-consuming to machine using traditional subtractive manufacturing methods. Materials such as titanium, and so-called ‘superalloys’, including those from the Inconel, Waspaloy, and Hastelloy series, have already been used in 3D printed components for high-stress applications (Zhang et al., forthcoming; Wang, 2012). Inconel has been used in components for 3D-printed firearms, and additive manufacturing is likely to prove a cost-effective way to use other existing and newly developed materials that are otherwise hard to machine.

Further, advanced 3D-printing techniques can provide for the development of simple, robust designs which require minimal or no hand assembly, while containing complex moving parts. Reducing the requirements for fasteners, welds, and adhesives, as well as the associated labour involved in performing these tasks, can make it more cost-effective to produce complex parts.¹⁶ Large corporations, including BAE Systems and General Electric and its subsidiaries, have begun to embark on redesigning complex assemblies that would traditionally contain dozens of individual parts into unitary parts that can be manufactured by a 3D printer in a single operation (Catts, 2013; Elwell, 2014).

Additive manufacturing techniques can also allow for the efficient, cost-effective production of hollow or partially hollow parts for applications where it is essential to minimise weight. Imperial Machine & Tool Co. of New Jersey in the United States has developed a large nut for the M777 howitzer that replaces solid metal with an internal lattice structure. The new nuts are just as strong as those produced using traditional manufacturing methods, but only half the weight (Zelinski, 2014).

3D printing also makes it possible to customize parts far more cheaply than traditional manufacturing processes can achieve, greatly reducing the need for hard tooling and fixtures. It is likely that major firearms manufacturers will seek to capitalize on the potential of 3D-printing technology to produce complex, personalized components. Components such as buttstocks, pistol grips, fore ends, and triggers will be able to be customized with little AM time and only minimally increased costs of components compared to current methods. Eventually, it will be possible to produce highly complex assemblies such as suppressors and fire-control groups far more cheaply due to the simplification of the manufacturing process.¹⁷

Policy considerations

Rapid advances in 3D-printing technology and its increased application to the manufacture of firearms and firearms components raise a number of legal, normative, and law-enforcement questions. Although many national governments have highlighted the issue, as have regional and international bodies such as the Organization for Security and Co-operation in Europe (OSCE), very few reports on the matter have been compiled or made publicly available (see OSCE FSC, 2014). In general, national and international controls apply to 3D-printed firearms in the same way as they do to traditionally manufactured firearms, but the new technology will pose new challenges in the area of enforcement.

Regulation of firearms manufacturing

Most governments regulate firearms manufacturing to some extent, although the degree of regulation varies from country to country. In the United States, for example, unlicensed individuals may produce firearms for personal use, provided they do not sell or transfer the finished product (USDOJ, 2005). These laws apply regardless of the manufacturing techniques used to produce the firearm, which means that in many cases individuals can legally produce 3D-printed firearms. Nevertheless, individuals producing their own firearms must still comply with relevant US state laws, which may restrict the type of firearm they may produce, and where they may carry or use it.

Other countries do not permit the unregulated manufacture of firearms. In Japan, for example, the manufacture of firearms is regulated by the Weapons Manufacture Law (Japan, 1953). Any person intending to manufacture firearms must obtain a permit from the Ministry of Economy, Trade and Industry (METI). There are similar restrictions on firearms manufacture in many other countries, and these would normally apply to 3D-printed firearms (and their components, as applicable) in the same way as they do to firearms produced using traditional manufacturing methods.

International controls also apply to the manufacture of 3D-printed firearms. There is no reason to assume that the provisions in the United Nations Small Arms Programme of Action (PoA),¹⁸ dealing among other things with the illicit manufacture of small arms and light weapons, would not apply to weapons produced using AM techniques. Paragraph II(2) of the PoA requires states to ‘exercise effective control over the production of small arms and light weapons within their areas of jurisdiction ...’ in order to prevent illegal small arms manufacture, trafficking, and diversion. Paragraph II(3) requires states to make the illegal manufacture of small arms and light weapons a criminal offence, while Paragraph II(6) requires states to take steps to identify and take action against groups and individuals engaged in the illegal manufacture of small arms and light weapons (UNGA, 2001b).

The Firearms Protocol¹⁹ is also relevant to the regulation of firearm manufacturing. Article 3(d) defines ‘[i]llicit manufacturing’ for the purposes of the Protocol, requiring anyone manufacturing or assembling a firearm to hold ‘a licence or authorization from a competent authority of the State Party where the manufacture or assembly takes place’ and to ensure the firearms are marked at the time of manufacture in accordance with the provisions of the Protocol. Article 5.1(a) also requires states to criminalize, when committed intentionally, the ‘illicit manufacturing of firearms, their parts and components and ammunition’ (UNGA, 2001a). These international control measures would apply to firearms produced using additive manufacturing techniques in the same way as they apply to traditionally manufactured firearms.

Marking, record-keeping, and tracing

In many cases, national or regional laws subject all firearms to stringent marking practices at the time of production. For example, EU Directive 2008/51/EC requires all EU member states to ensure that firearms manufactured in their jurisdiction are marked to enable tracing. Drawing on equivalent provisions in the Firearms Protocol and the International Tracing Instrument (ITI)²⁰ (UNGA, 2001a, art. 8(1)(a); 2005, para. 8(a)), the Directive obliges members to either ‘require a unique marking, including the name of the manufacturer, the country or place of manufacture, the serial number and the year of manufacture (if not part of the serial number)’ or to ‘maintain any other unique and user-friendly marking with a number or alphanumeric code’ that allows easy identification of the country of manufacture by all members (Directive 2008/51/EC, paras. 2(a) and (b), amending art. 4, para. 2; EU, 2008).

Some states do not require private individuals to mark firearms they personally produce, under certain circumstances. For example, the United States does not require unlicensed individuals to mark a firearm with a serial number or other information, provided they do not sell or otherwise transfer ownership of the weapon (US, 1968, s. 921(a)(3)). Where national legislation requires the marking of firearms, without exception, it would apply to 3D-printed weapons in the same way as other firearms (see ATF, n.d.).

In fact, the marking provisions of the Firearms Protocol and ITI make no exception for unlicensed individuals; states are to ‘require’ that firearms (Protocol) or small arms and light weapons (ITI) be marked in a certain way ‘[a]t the time of manufacture’ (UNGA, 2001a, art. 8(1)(a); 2005, para. 8(a)).

Paragraph 7 of the ITI also states that:

The choice of methods for marking small arms and light weapons is a national prerogative. States will ensure that, whatever method is used, all marks required under this instrument are on an exposed surface, conspicuous without technical aids or tools, easily recognizable, readable, durable and, as far as technically possible, recoverable.

With many 3D-printed firearms and firearms components (including components which regularly bear manufacturer and serial markings, such as

receivers) being constructed from polymers, these may not comply with the 'durability' requirement of the ITI (see Chapter I). Although the Firearms Protocol and the ITI both include measures against the removal or alteration of markings (UNGA, 2001a, art. 5(1)(c); 2005, art. 8(e)), in practice it is much easier to tamper with or entirely remove markings made on polymer than on metal.

The production of firearms without markings, including the assembly of complete firearms from unmarked components, is another way to circumvent the tracing of weapons used in crime or illicitly trafficked. In order to prevent this, the ITI stipulates that:

a unique marking should be applied to an essential or structural component of the weapon where the component's destruction would render the weapon permanently inoperable and incapable of reactivation, such as the frame and/or receiver (UNGA, 2005, art. 10).

In this case, too, the ITI makes no exception for unlicensed individuals.

Regulation of international transfers

3D-printed firearms and firearms components fall squarely within the scope of existing international instruments regulating the international transfer of small arms and light weapons. These include the PoA (UNGA, 2001b, Section II, paras. 11–15), the Firearms Protocol (UNGA, 2001a, Arts 3(e), 5(1)(b), 10–11), and the Arms Trade Treaty (UNGA, 2013).²¹ The content of these instruments mean that the method of production is irrelevant.

National legislation may apply to the digital files used in the design and manufacture of 3D-printed firearms, and posting these online may constitute 'exporting' restricted defence data. In May 2013 the US Department of State²² directed Defense Distributed to remove design files related to the Liberator handgun from its website. It noted that by posting these files online, Defense Distributed had potentially contravened the Arms Export Control Act (AECA) (22 U.S.C. 2778) and the AECA's implementing regulations, the International Traffic in Arms Regulations (ITAR) (22 C.F.R. Parts 120–130). The AECA and the ITAR impose restrictions on the transfer of and access to controlled defence articles and related technical data. The restricted items

and data, including firearms and technical data relating to firearms, are designated in the United States Munitions List (USML) (22 C.F.R. Part 121) (Cooke, 2013).

Law-enforcement challenges

3D manufacturing will not render current international and national controls on firearms obsolete. It may, however, make applying these controls more difficult, in effect posing new law-enforcement challenges. As AM technologies continue to improve and become more readily available to private individuals, it will become increasingly difficult to enforce regulations on firearm manufacturing. In some countries, such as the United States, where the private manufacture of firearms is legal under certain conditions, the challenges to law enforcement may be largely limited to the transfer or sale of 3D-printed firearms produced without a licence and/or without legally required markings.

To a large extent, the methods of law enforcement are likely to remain unchanged in relation to the interdiction of firearms that have been stolen or produced illegally using traditional manufacturing methods. The lack of markings on illicit 3D-printed weapons will preclude standard tracing, however. In countries where the private manufacture of firearms is illegal, the advent of 3D-printed firearms is likely to pose more significant law-enforcement challenges.

In countries that regulate only certain essential components of a firearm, for example frames or receivers, 3D-printing technology may be employed to produce these components in order to avoid registration requirements. Additive manufacturing may also be used to produce other components that are restricted in certain jurisdictions, such as components allowing firearms to be converted from semi-automatic to automatic (selective fire) capability, or muzzle attachments such as sound suppressors.

In June 2014, Yoshitomo Imura was arrested in Kanagawa prefecture, Japan, and charged with the possession of firearms manufactured using 3D printing. As he had produced them without a licence, officials asserted that he was in violation of the country's Weapons Manufacture Law (Japan, 1953; Coldewey, 2014). Some legislators argue that the private manufacture

of 3D-printed firearms should be prohibited; it is unclear, however, why 3D-printed firearms would be specifically targeted in countries that permit private individuals to produce firearms using traditional manufacturing methods, or whether such a prohibition would be effective. In any case, several governments have recently tabled legislation to ban or otherwise restrict 3D-printed firearms and firearm components. Steve Israel, a US Democratic congressman, attempted, unsuccessfully, to ban 3D-printed firearm components in an amendment to the federal Undetectable Firearms Act in 2013 (Greenberg, 2013a). A bill introduced into the Queensland State Parliament in Australia in May 2014 seeks to regulate ‘digital 3D and printed firearms’ (Australia, 2014).

Some observers have called for controls to be placed on 3D printers, certain materials used in the manufacture of 3D-printed firearms, and even digital CAD or similar files (see, for example, Sakamoto and Takeuchi, 2014). Many in the industry have objected to these controls, pointing out that firearms manufacture is only one use of 3D printers and printing materials—overall, a very minor part of the wider AM industry (Baartz, 2014). In fact, there are no materials that have been specifically designed for the 3D printing of firearms, or that are more suited to the printing of firearms than other items. Restricting access to certain high-strength polymers or metal alloys in printer-ready state, while feasible, would almost certainly have adverse effects on the wider AM industry.

Restrictions on CAD, STL, and similar file formats used in the design and production of 3D-printed firearms (as discussed above) could prove especially difficult to enforce. As attempts to tackle digital piracy have shown, it is almost impossible to control the flow of information over the Internet once released into the public domain. Over 100,000 people downloaded the Liberator design files in the two days they were hosted on Defense Distributed’s website, before the US Department of State advised the company of an apparent ITAR violation (Neal, 2013).

Policy-makers in some jurisdictions may also need to consider the legal definition of what constitutes the manufacture of a firearm. With the increasing popularity of ‘maker spaces’,²³ where individuals can share the use of infrastructure and manufacturing equipment, people may be able to print

firearms on a 3D printer owned by a third party (group or individual). Laws addressing the illicit manufacture of firearms, including those produced using AM techniques, will need to determine the culpability of third parties in cases where machinery is made available to people who may wish to produce firearms.

Some governments have enacted specific legislation on firearms that are difficult to detect using conventional security methods. Some polymer 3D-printed firearms, such as the Liberator, if produced without the specified metal block, will be largely undetectable by certain security screening methods, such as metal detectors. This feature may appeal to individuals or groups seeking to smuggle a firearm into a secured area. Other screening methods, such as backscatter X-ray body scanners, would be able to detect such firearms, at least under certain conditions. Some observers have suggested that the addition of contrast agents to certain high-strength polymers may help to make them more readily detectable by X-ray machines.²⁴ The US Undetectable Firearms Act, originally passed in 1988 and extended in 2003, was scheduled to expire in December 2013, but was extended until 2023 amidst debate about the adequacy of the original Act in light of the development of 3D-printed firearms (Kasperowicz, 2013). It is important to note that 3D-printed ammunition does not exist, and that 3D-printed firearms such as the Liberator or Solid Concepts 1911 use conventional ammunition, which is readily detectable through existing means.

3D-printed firearms may also pose a challenge to traditional investigative methods. Given the low cost and accessibility of some polymer weapons, they could be considered 'disposable' and be incinerated or otherwise destroyed after having been used in criminal activities, or if action by law-enforcement personnel is suspected. The lack of rifling on some 3D-printed firearms may also limit the application of ballistic forensics techniques that match fired projectiles to a specific firearm based on the unique pattern of the weapon's rifling. Projectiles that had been fired from an unrifled barrel, however, would instantly raise suspicion if recovered from a crime scene, as unrifled firearms (with the notable exception of shotguns, firing distinctive projectiles in most cases, and converted blank-firing weapons or other improvised firearms) are rarely used for criminal purposes. Modern forensic

examinations of projectiles also match markings on the projectile to the unique tool marks found in the bore of a specific firearm. In some 3D-printed firearms, such as the Liberator, the use of an improvised firing pin will result in distinctive firing-pin impressions, which could be used to match a fired cartridge case to a specific firing pin. However, such firing pins could easily be exchanged or discarded. Other forensic techniques can also be used to match projectiles with firearms with polymer barrels, such as the Liberator.²⁵

As with any emerging technology, it will be important to provide for the training and education of law-enforcement personnel. Otherwise, law-enforcement efforts risk being ineffective and prone to error. In October 2013, officers from the Greater Manchester Police in the UK raided a home and seized items they claimed were 3D-printed firearms components. In fact, they were components for a 3D printer (BBC News Manchester, 2013; Estes, 2013).

Other policy implications

The additive manufacturing of firearms is also likely to raise other policy issues, such as concerns related to manufacturing standards, including user safety. For amateur users of the technology, a lack of familiarity with or the failure to adhere to strict firearms industry standards could well pose a threat to public safety (such as the risk of catastrophic firearm failure). It also appears likely that firearms produced by methods that do not comply with industry standards will have significantly shorter lifespans than their commercial counterparts and break down more easily. Those involved in the industry have also found it difficult to insure 3D manufacturing businesses, especially those related to the manufacture of firearms or firearms components.²⁶

Conclusion

Most analysts believe that the 3D-printing industry will experience a period of rapid growth in the near future. They anticipate that growth will be both in high-end manufacturing and design and in consumer-level printing. In fact, consumer-grade printers are poised to become more advanced and less

expensive as a number of patents expire. Nevertheless, advanced machinery, such as that which produced the Solid Concepts Inc. 1911 DMLS pistol, will almost certainly remain out of the reach of individuals for some time.

Online CAD libraries now contain a range of blueprints for printing complete firearms, components, and accessories.²⁷ Translating them into finished products, however, requires a considerable level of skill, in effect limiting consumer-level activity to committed hobbyists and amateurs. Individuals seeking to make a firearm using 3D printing need to undertake significant preparatory and finishing work, as most firearm parts require finishing by hand post-printing. It is certainly not a case of ‘click, print, fire’, as is often assumed. Such assumptions are even less realistic in relation to 3D-printed metal firearms, or more advanced firearms. It is simply false to claim that anyone with a 3D printer can quickly and easily produce assault rifles, for example (Chernicoff, 2012).

Private individuals and small groups currently face several important obstacles to the manufacture of 3D-printed firearms. These include the cost of printers and materials, the technical skills required, and the ability of the materials to withstand the temperatures and pressures associated with firearms (Birtchnell and Gorkin, 2013; Ferguson, 2014). In itself, there is nothing new about a private individual or small group being able to craft produce a firearm. Criminals and armed groups around the world produce a range of improvised firearms from various materials using traditional or ‘backyard’ methods. Some improvised firearms are quite advanced, and fully automatic weapons of this kind are frequently captured from non-state armed groups. Most importantly, the capabilities of the vast majority of these weapons outstrip those of any 3D-printed firearm that can currently be manufactured at the consumer level. More technological expertise is required to print and assemble a 3D-printed firearm than to produce many other ‘backyard’ expedient firearms with more significant capabilities.

At this stage, the only benefits that economically viable 3D-printed weapons may hold for individuals or non-state groups seeking illicit weapons lie in their untraceable nature and in the polymer construction that prevents many common screening devices from detecting them. Although printing a firearm in its entirety, with no markings, will normally make the weapon

untraceable, many traditional firearms can also be rendered untraceable with relative ease. Markings can be filed off or may, in some cases, be absent, depending on applicable marking practices. On the other hand, the relatively undetectable nature of some largely polymer 3D-printed firearms may appeal to those seeking illicit firearms with this characteristic—in order, for example, to smuggle a weapon into a secured area. Indeed, Liberator-type handguns are already being sold online through illicit marketplaces (Welch, 2014).

Moreover, when the costs of purchasing or producing 3D-printed firearms are considered together with their operational limitations, traditional firearms purchased on the black market are likely to remain far more appealing to individuals and non-state armed groups for the foreseeable future. Pricing data indicates that firearms with significantly greater capability—such as fully automatic Kalashnikov-pattern assault rifles—can be often purchased for a few hundred US dollars (Killicoat, 2007). In some cases firearms can be purchased for less than USD 100. While polymer 3D-printed firearms, such as the Defense Distributed Liberator, can now compete on price in such markets, their significant limitations mean that even old or poorly maintained traditional firearms are likely to be of more practical value. 3D-printed metal firearms are of much higher quality but, as mentioned earlier, are currently vastly more expensive than their polymer counterparts. Barring significant technological advances, they are likely to remain beyond the reach of those seeking illicit weapons for many years to come. 📌

Endnotes

- 1 Author interviews with confidential industry sources, April 2014.
- 2 The Masada assault rifle is now known as the Bushmaster ACR and is produced by Bushmaster and Remington for the civilian and military markets respectively (author interviews with confidential industry sources, April 2014).
- 3 Although the FMG-9 did not enter production, the Magpul-PTS FPG, an airsoft derivative, was produced (author interviews with confidential industry sources, April 2014).
- 4 Sintercore LLC's 3DX was formerly known as the 'Auxetik'.
- 5 It is important to note that in neither the UK–France nor the Israeli example did the journalists in question smuggle the metal firing pin for the weapon or any ammunition into the secured locations.
- 6 Author interviews with confidential industry sources.

- 7 Author interviews with confidential industry sources.
- 8 The range of Liberator derivatives and features such as rifling, polymer type, and various reloading mechanisms has yet to be extensively tested. These areas require further research. Any ‘rifling’ printed from those polymers that are typically used to produce Liberator-type handguns is likely to be marginally effective, at best.
- 9 Unfinished receivers’ legal status is governed on a case-by-case basis by the ATF, using so-called ‘determination letters’ (see, for example, ATF, 2013b). In some recent cases the legal status of certain producers’ unfinished polymer lower receivers was uncertain (Michel and Associates, 2014).
- 10 More detailed information was not yet available. Ohio Ordnance Works were contacted for comment, but did not respond. Note that the term ‘furniture’ is used to refer to non-critical ergonomic components of a firearm, such as the fore end, pistol grip, or stock (Jenzen-Jones, forthcoming).
- 11 This may be an example of rapid prototyping in action.
- 12 Author interview with Neal Brace, CEO, Sintercore, LLC, 1 April 2014.
- 13 Some finishing is required on the threads, also made from Ti64.
- 14 Author e-mail interview with Didrik Sørli, application engineer, Tronrud Engineering AS, 5 June 2014.
- 15 Author interview with Neal Brace, CEO, Sintercore, LLC, 1 April 2014.
- 16 Author interview with Neal Brace, CEO, Sintercore, LLC, 1 April 2014.
- 17 Author interview with Neal Brace, CEO, Sintercore, LLC, 1 April 2014.
- 18 Full name: UN Programme of Action to Prevent, Combat and Eradicate the Illicit Trade in Small Arms and Light Weapons in All Its Aspects. See UNGA (2001b).
- 19 Full name: Protocol against the Illicit Manufacturing of and Trafficking in Firearms, Their Parts and Components and Ammunition, supplementing the United Nations Convention against Transnational Organized Crime. See UNGA (2001a).
- 20 Full name: International Instrument to Enable States to Identify and Trace, in a Timely and Reliable Manner, Illicit Small Arms and Light Weapons. See UNGA (2005).
- 21 Note that the ATF’s application to parts and components is partial (see Parker, 2014).
- 22 More precisely: the US Department of State’s Bureau of Political Military Affairs, Office of Defense Trade Controls Compliance, Enforcement Division (DTCC/END).
- 23 Also referred to, sometimes with subtle differences in meaning, ‘makerspaces’, ‘hacker spaces’, ‘hackerspaces’, ‘hacklabs’, and ‘techspaces’ (Hackerspaces.org, n.d.).
- 24 Author correspondence with Paul William, independent firearms industry specialist, 28 June 2014.
- 25 These techniques are not discussed for security reasons.
- 26 Author interview with Neal Brace, CEO, Sintercore, LLC, 1 April 2014.
- 27 These references have been withheld for security reasons.

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IV. New technologies and small arms control: Preventing unauthorized acquisition and use

Matt Schroeder

Introduction

The United Nations Programme of Action (PoA) regarding the illicit arms trade¹ calls on member states to exercise effective control over the production, export, import, transit, or retransfer of small arms and light weapons as a means of preventing the illegal manufacture or illicit trafficking of these items, or their diversion to unauthorized recipients (UNGA, 2001, para. II(2)). Fulfilling this broad mandate requires cost-effective action at many different levels. How could greater use of technology assist governments in implementing the PoA? What are the primary barriers to adopting new and under-used technologies?

This chapter makes a preliminary assessment of new and under-used technologies for marking and securely storing, transporting, and using small arms, light weapons, and their ammunition throughout their life cycle, ‘from cradle to grave’. It focuses on the following phases of this cycle and related activities: production (marking), storage and transport (physical security and stockpile management (PSSM)), and final use (preventing unauthorized use). It is beyond the scope of the chapter to comprehensively assess all new and under-used technologies. Rather, it surveys some of the most prominent technological developments in order to illustrate both the potential impact of these technologies on efforts to control small arms and the numerous barriers to fully realizing their potential.

Advances in technologies for small arms are, in fact, blurring the various life-cycle stages as they apply to control measures. Some technologies for preventing the unauthorized use of small arms are also designed to serve as the main interface for computerized stockpile-management and security systems. Such systems, in turn, serve as repositories for data that are essential for tracing lost, stolen, or diverted weapons.

While some of the technologies discussed in this chapter are indeed new, most were developed many years ago and are frequently used in other sectors. Since the producers and users of small arms and light weapons have been slow to embrace these technologies, they are still considered new in the context of small arms life-cycle management. This lag is explained by many factors, several of which are identified and explained below.

The chapter first assesses new and under-used technologies related to marking, record-keeping, and tracing; PSSM; and preventing the unauthorized use of small arms and light weapons. It makes brief references to significant changes that could enhance the performance or increase use of these technologies. The chapter then identifies some of the main obstacles to wider adoption of these technologies, and concludes with observations regarding the inherent limitations of new technologies—and technology in general—for preventing the theft, loss, and unauthorized use of small arms.

Marking, record-keeping, and tracing

Recognizing the importance of marking, record-keeping, and tracing² to combating the illicit trade in small arms, the PoA includes several paragraphs on these activities (UNGA, 2001, paras. II(7)–(10)). More importantly, the drafters of the PoA initiated a process that led to the adoption of the International Tracing Instrument (ITI)³ in 2005 (UNGA, 2001, para. IV(1)c). The ITI requires governments to mark small arms and light weapons at the time of manufacture and, to the extent at the time of import (UNGA, 2005, paras. III(8)a and III(8)b); to keep ‘accurate and comprehensive’ records of all marked small arms (para. IV(11)); and to establish a system for tracing illicit weapons and responding to trace requests from other governments in line with ITI requirements (para. V(14)).

Law-enforcement officials use markings on small arms and light weapons to trace seized and stolen weapons to their last known (authorized) recipients. To obscure the origins of their firearms, some criminals attempt to obliterate the serial numbers and other markings. Law-enforcement agencies are often, but not always, able to recover the markings. Additional markings

placed on concealed areas of the weapon can facilitate tracing when defaced markings are irretrievable.⁴

There are two main approaches to marking small arms and light weapons: deformation and engraving (i.e. material removal). The former includes marking methods that deform the surface of the marked material, through either compression or impact. Stamping is the most common method of marking through deformation. Other methods include dot peen, also known as pinstamping or micro-percussion. Engraving involves the removal of material from the marked surface by mechanical means (i.e. with diamond cutters, hardened pins, or rotation carbide cutters) or with lasers, including diode-pumped and fibre lasers (Persi Paoli, 2010, pp. 2–5).

This chapter does not include an in-depth summary of the comparative advantages and disadvantages of the above-mentioned marking methods, which are thoroughly documented elsewhere (see Persi Paoli, 2010). In short, stamping and dot-peen machines are generally cheaper to buy and consume less energy than laser-marking machines. Markings made by stamping machines that are later defaced are also often more easily recovered than markings made by other types of machine. Lasers are the fastest marking method and are often better for applying markings on fully assembled weapons (Persi Paoli, 2010, pp. 9–10). The life-cycle costs of lasers are often lower than mechanical marking machines due to their durability, minimal maintenance requirements, and low failure rates.⁵ Lasers are also generally better suited to the marking of polymer (plastics) (UNGA, 2014, para. 22; Persi Paoli, 2010, p. 10).

Recent developments in technology for marking weapons have been modest. Laser-marking machines have become cheaper and are reportedly more reliable.⁶ According to one industry representative, the maintenance of their laser-marking machines is typically no more than an annual half-day visit by a technician, often scheduled during a public holiday period to avoid interrupting production.⁷ While the cost of lasers has decreased compared to other marking machines, prices still range from approximately EUR 15,000 to 80,000 (USD 18,700–100,150), depending on the machine and the difficulty of integrating it into existing production processes.⁸



Image 1. **2D data matrix code**

© Traceability Solutions

More noteworthy are new developments in the markings themselves and improvements in the associated scanning technology, which have potentially significant implications for record-keeping and tracing. Traceability Solutions, for example, offers a system for marking, recording, and retrieving information on firearms in the form of two-dimensional data matrix codes (see Image 1).⁹

According to Traceability Solutions, its data matrix code is capable of conveying many details about the weapon, but, to keep the code smaller and easier to read, it is often limited to a unique, randomly generated 12-digit 'Industrial Fingerprint' (IFP).¹⁰ The IFP serves as the reference link to information on the weapon that is stored in the relevant databases, including the make, model, country of manufacture, and serial number. Through the use of biometric and two-dimensional direct part marking (DPM) scanners, the marked firearm can be linked to data on the individual to whom it is assigned, including the person's competency certificates, ammunition allocation, and other relevant information. While the codes themselves were introduced more than a decade ago, the scanners used to read them were

not reliable. Advances in scanning technology, along with improvements in database software, have reportedly made these systems more user-friendly.¹¹

Another technological development of relevance to the ITI is micro-stamping—the process by which a unique, traceable code is inscribed onto one or more components of the firearm and subsequently imprinted onto the weapon’s ammunition as it is fired (Chumbley et al., 2012, pp. 145–46). A commonly referenced technique involves the engraving of tiny symbols onto the firing pin with high-powered lasers. When the firing pin strikes the cartridge, the symbols are stamped onto the cartridge case. Alternative (or complementary) methods include the placement of markings on other components of the firearm, such as the barrel (Cork et al., 2008, pp. 262–63).

In theory, microstamping allows investigators to identify and trace ammunition components to guns that have been used in criminal activities even when the guns are not accessible, and also to identify the last retail purchaser of the firearms linked to the ammunition (Cork et al., 2008, p. 255; UNGA, 2014, para. 26). Assuming that reading the codes does not require specialized forensic equipment or expertise, the routine use of microstamping would also reduce the workloads of overstretched forensic examiners (Chumbley et al., 2012, p. 147).

These technologies have the potential to improve record-keeping and tracing by enabling investigators to instantly capture, store, and retrieve key data about each firearm in a given storage facility, the authorized users to whom each weapon is issued, and the usage history of each weapon. The widespread use of such systems could have significant implications for tracing lost, seized, and stolen weapons, thereby enhancing the accountability of the end-user. Fully exploiting these capabilities requires resources and expertise, however. For example, efficiently collecting, storing, and retrieving data on microstamp identifiers will require some government agencies to create new databases and others to expand or repopulate existing databases. The capacity to integrate this and other data into existing IT infrastructure varies across different agencies, and this is likely to pose significant challenges for some governments, as explained later in this chapter.

Physical security and stockpile management

The PoA calls on UN member states to ensure that their security forces ‘establish adequate and detailed standards and procedures relating to the management and security of their stocks of these [small arms and light] weapons’. These standards and procedures are to include ‘physical security measures; control of access to stocks; inventory management and accounting control ... [and] accounting and control of small arms and light weapons held or transported by operational units or authorized personnel’ (UNGA, 2001, para. II(17)). These provisions reflect well-founded concerns about the security of small arms and light weapons held by military and police forces, thousands of which are looted, lost, or stolen each year.

There are several technologies that, in theory, have the potential to improve stockpile management and security in line with the PoA. These technologies are designed to prevent unauthorized access to stored weapons, improve the accuracy of inventory records, track the use of weapons, and monitor and protect weapons in transit. An example is Baselock, a handgun storage system manufactured by the company Armatix. Baselock consists of one or more modules, each of which comprises a mechatronic locking element, a fingerprint scanner, and a numeric touchpad. According to Armatix, the modules can be mounted on the floors, shelves, and walls of storage facilities, and in transport vehicles. Insertion of the locking element into the gun’s barrel renders the weapon inoperable until a user enters a PIN code, touches the fingerprint scanner, or uses a remote transponder. When connected to a storage facility’s IT network, facility personnel can use Baselock to control access to stored weapons, monitor their removal and return by authorized users, and quickly retrieve data and documentation on the weapons (Armatix, n.d.a.; n.d.b).¹² The Malaysian company HeiTech Defence Systems offers a similar product called the Weapons Management & Surveillance System. It employs a combination of networked databases, gun racks, infra-red and CCTV monitoring systems, and gun-barrel sensors and locking systems to control and track the storage and deployment of firearms (HeiTech Defence Systems, n.d.).

Other technologies for securing stockpiles and managing inventories include biometric gun safes,¹³ software for tracking firearms inventories and

sales,¹⁴ and fingerprint-activated trigger locks.¹⁵ Many of these products are relatively inexpensive and can be purchased online from numerous vendors. Biometric gun safes, for example, can be purchased for approximately USD 100 through the US online retailer, Amazon.com (Amazon.com, n.d.).

Increased computing power and other IT advances are also enhancing the capacity of security forces to monitor and track small arms and light weapons during shipping and transport. One such example is the US military's Defense Transportation Tracking System (DTTS), which was introduced in 1989 and subsequently upgraded. Through the DTTS, each day the US military tracks 150 to 300 shipments of sensitive cargo, including small arms and ammunition, in almost real time from their origin to their destination using satellites and other communications technologies (Miles, 2012). The system draws on more than 400 data sets worldwide to monitor traffic patterns and accidents, weather, and other conditions that could affect the delivery schedule, routing, or security of the shipment. In certain cases, DTTS operators also have access to live traffic camera feeds on the shipment route (GeoDecisions, 2007; n.d.; see Image 2).

Upgrades to the system allow the US military to track shipments by various forms of transport (road, rail, and sea), and to detect when a truck trailer door is opened or the trailer is unhitched (Johnson, 2010), which may be signs of attempted theft or diversion. Gun safety mechanisms such as Quicklock¹⁶ can also help secure weapons during transit, including in high-risk environments such as conflict zones, where shipments of weapons are often most vulnerable (Armatix, n.d.c).

Another technology frequently identified as potentially useful for in-transit PSSM is radio frequency identification (RFID). RFID tags and strips are currently used to monitor, record, and track the physical movement of a wide array of military and commercial goods, including shipments of arms and ammunition (UNGA, 2014, para. 26; Persi Paoli, 2011).¹⁷ Like other technologies profiled in this chapter, RFID has been widely used in a variety of military and commercial applications for many years.¹⁸ New uses of RFID technology could make it much easier to monitor and track shipments of small arms and light weapons. For example, a prototype of an RFID-enabled e-seal recently developed by researchers in Australia enables exporters

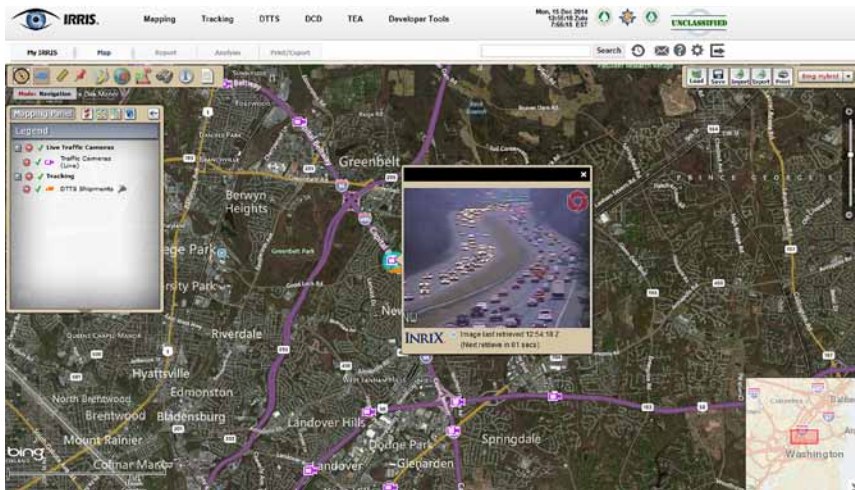


Image 2. Screenshot from the Intelligent Road/Rail Information System © GeoDecisions (n.d.)

efficiently to track large numbers of individual crates of small arms and ammunition and also to monitor the physical integrity of the seals on those crates. In other words, RFID scanners can instantly detect when the e-seal on an individual crate in a shipment has been broken or otherwise compromised, which could be a sign of theft or diversion (Cole and Hu, 2011.) Rapid detection of unauthorized access to arms shipments would allow the shipper to take steps to prevent further theft.

End-use control

Devices for preventing the unauthorized use of small arms and light weapons have the potential to prevent criminals and other prohibited persons from using trafficked and diverted weapons. Most of these devices, hereafter referred to as electronically controlled safety mechanisms (ECSMs),¹⁹ fall into one of two categories: biometric and token-based. Biometric technologies ‘utilize unique features of individuals as the “key” to identify authorized users’ (Greene, 2013, pp. 24–27). Examples of technologies used in biometric ECSMs include finger- and palm-print scanners; grip, voice, and facial recognition; and skin spectroscopy.

Token-based technologies differ from biometric technologies in that the device that enables the weapon is contained in a separate object, or token, which may or may not be personalized. Most token-based ECSMs employ RFID technology, consisting of an RFID reader and tag. The reader is typically installed in the firearm and the tag is placed in the token, which takes many forms, including rings, gloves, wristbands, and wrist watches (Greene, 2013, pp. 24–25, 38, 47).

In theory, the widespread use of ECSMs would advance key goals of the PoA by helping to reduce unauthorized use—and, by extension, the trafficking—of small arms and some light weapons. Equipping firearms with ECSMs could reduce the number of security officers injured or killed by assailants who gain access to their weapons (or the weapon of another security officer). ECSMs could also deter the theft and seizure of firearms from security forces and other authorized users, and prevent the unauthorized use of lost weapons. In reality, the net effect on trafficking and unauthorized use depends on several factors, including the difficulty of circumventing or otherwise defeating the ECSMs, the security of tokens and PIN codes for token-based technologies, and the false positive rate²⁰ of biometric technologies. For example, a semi-automatic pistol equipped with a biometric ECSM whose key components cannot be removed without destroying them and which has a very low false positive rate would presumably be of little value to arms traffickers and their clients.²¹

Many of the technologies identified above are widely used in other industries, and programmes aimed at incorporating them into firearms date back at least two decades. Nonetheless, sales of firearms equipped with ECSMs have been modest to date. Some promising technologies are still in development, and it may be many years before they are available for purchase. Of the 13 ECSMs assessed for their technological maturity by the National Institute of Justice in 2013, only three were categorized as an ‘Advanced Prototype or Production-Ready Design’.²² The remaining ten systems were deemed to be less technologically mature (Greene, 2013, pp. 27–33), and some have been dormant for years due to funding issues or a perceived lack of demand. Whether these 13 projects will eventually yield commercially viable products remains to be seen.

Yet even ECSMs that are more technologically mature are struggling to gain a foothold in military, law-enforcement, or commercial markets. Interviews with industry representatives and a review of the existing literature point to several likely explanations, as discussed below.

Barriers to adopting new and under-used technologies

There are numerous and diverse barriers to the widespread and effective uptake of the technologies identified above. Some of these barriers apply to many such technologies while others are primarily applicable to ECSMs. This section briefly describes these barriers.

Cost and budget limitations are factors that apply to varying degrees to most of the above technologies. Some systems, such as the US DTTS, cost many millions of dollars to assemble, operate, and update. It would be very difficult for smaller or less well-funded military forces to replicate this system. While less costly than DTTS, other technologies for securing small arms still require significant funding. The purchase and installation of Armatix's Baselock system, for example, costs EUR 300–800 (about USD 400–1,000) per firearm.²³ This expense may be recouped through reductions in personnel costs over the mid- to long term, but the initial investment is significant and thus installation of systems such as Baselock is likely to be deferred until large-scale renovation of the existing physical security infrastructure is deemed necessary.

The costs associated with microstamping could also be significant. These costs include not only the acquisition and maintenance of marking equipment, training for operators of the marking machines, and optimization of the mark for each firearm model, but also indirect costs, such as the effect of microstamping on production processes and rates (Chumbley et al., 2012, p. 146).

Cost may also limit sales of firearms equipped with ECSMs, including to government agencies. The Armatix iP1 pistol and accompanying wristwatch cost USD 1,798 (Rosenwald, 2014c)—considerably more than most conventional pistols on the market, including the models commonly procured by security agencies. The unit cost for large orders of iP1 pistols would be lower

than the retail price for individual units, but it is unclear whether, and at what point, these economies of scale would make ECSM-equipped firearms competitive with their conventional counterparts in terms of price.

Adoption of many of these technologies is also hindered by infrastructural and logistical barriers. Systematically digitizing and networking small arms inventory records are complicated endeavours that can take many years to complete. In poorer countries, inadequate physical and IT infrastructure and a lack of qualified personnel make these tasks even more challenging. These issues are apparent in ongoing efforts to develop and implement automated inventory-management systems in Afghanistan. In 2006, the Afghan National Army introduced its Core Inventory Management System (CoreIMS), an off-the-shelf automated inventory-management system purchased and set up with US government assistance. CoreIMS comprises records on small arms and other equipment received by the Afghan National Army and includes a description of individual weapons and their serial numbers, the receipt and issue dates for the weapons, and the Afghan National Army units to which they are issued (US DOD IG, 2008, p. 16).

Barriers to effectively establishing and maintaining CoreIMS and other automated systems in Afghanistan include a lack of consistent and reliable electrical power, inadequate IT infrastructure, and low literacy rates (US DOD IG, 2008, p. 59). At one depot visited by US military inspectors in 2009, inventory managers lost access to the system during power failures, which are 'a frequent or daily occurrence throughout Afghanistan', according to inspectors. They also noted that the handbook for the system was of little use because many Afghans are illiterate (US DOD IG, 2009, pp. 15–16).

For these and other reasons, the Afghan National Army's digital inventory of its small arms was incomplete eight years after CoreIMS was first introduced (US SIGAR, 2014, p. 7). More significantly, the Afghan National Police still does not have an automated system, relying instead on 'a combination of hard copy, hand written records, and some Microsoft Excel spreadsheets'. US Defense Department officials and their counterparts in the Afghan National Security Forces started developing an automated system for the police in 2010, but as of 2014 the system had still not been deployed and no implementation date had been established (US SIGAR, 2014, p. 6).

These problems are not unique to Afghanistan. In many less developed countries, the barriers to digitizing and networking data on small arms are as—or more—daunting than those in Afghanistan. In some African countries, weapons are stored in huts, abandoned schools, and corrugated steel shacks (Schroeder, 2013, p. 41). These facilities often lack steady access to electricity, let alone the IT equipment, software, and expertise required to create and maintain integrated networks that are comparable to those deployed in developed countries. In poorer countries, meeting basic PSSM requirements is likely to be prioritized over establishing digital inventory-management systems.

The stove-piping of data on weapons inventories by government agencies is another barrier to fully harnessing the potential of new technologies. Data linked to barcodes, matrixes, and other machine-readable codes marked on weapons is usually accessible only to custodial agencies (i.e. the agencies that issued and are responsible for the weapons) whereas the alphanumeric markings currently in widespread use can be read by anyone. Authorities attempting to trace a gun used in criminal activities that is marked with a data matrix code may, in theory, have access to much more data about when and from whom the weapon was diverted, but only if the investigators can identify, and secure the cooperation of, the issuing agency. For this reason, conventional alphanumeric markings are still essential.

Concerns about the maturity and reliability of new technologies also explain why some individuals and institutions are reluctant to adopt them, particularly ECSMs. There are fears that adverse physical conditions, battery failure, electromagnetic interference, or sabotage²⁴ could render the devices inoperable during an armed engagement (Haubursin, 2014). These concerns are summarized by James Pasco, Executive Director of the Fraternal Order of Police's advocacy centre in Washington, DC. '[ECSM-equipped firearms] can't just work 95 per cent of the time,' Pasco told United Press International in 2014, '[y]ou're not going to pick up a gun to shoot it unless you mean business. And if you mean business, that's when you absolutely don't need it to fail you' (Haubursin, 2014). According to industry representatives, efforts by the manufacturers of ECSMs to allay these concerns are hindered by the lack of clearly articulated and specific standards of reliability.²⁵

Similarly, critics of microstamping question its reliability as a law-enforcement tool. Some analysts claim that the codes on marked ammunition are frequently illegible and that the technology is 'easily defeated in seconds by using common tools' or by replacing engraved with un-engraved components (NSSF, 2013).²⁶ One recent study found that optimized microstamps are capable of successfully transferring the codes to most rounds fired during testing, although the transfer rate was lower for certain models of firearms and was adversely affected by the presence of lacquer on the ammunition (Chumbley et al., 2012, pp. 149, 153).²⁷ Critics also point to the ease with which identifiers can be circumvented or destroyed. Criminals can simply replace the firing pin and other components engraved with identifiers, or use household items to deface the identifiers. Placing identifiers on several components in the same firearm would mitigate but not entirely resolve this problem (Chumbley et al., 2012, p. 146).

Opposition from political and consumer groups may also explain the slow embrace of some of these technologies, including ECSM-equipped firearms. The effects of this opposition are most apparent in the United States, where activists have thwarted efforts to sell handguns with ECSMs. Firearms retailers in California and Maryland stopped selling the Armatix iP1 after receiving threats of physical violence and store boycotts from gun rights advocates, who feared that sale of ECSM-equipped handguns would lead to a ban on their conventional counterparts (Rosenwald, 2014a; 2014b). The fear stems, in part, from a New Jersey law that requires firearms dealers to sell only personalized (ECSM-equipped) handguns within three years after such handguns are available for retail sale anywhere in the United States (State of New Jersey, 2002).²⁸ Legislators in California and in the US Congress have introduced bills with similar requirements, fuelling concerns that the prohibition in New Jersey will be adopted by other states and perhaps at the federal level.

Other barriers to the adoption of the new technologies identified above include the conservative nature of military and law-enforcement agencies and the historically slow pace of change in firearms technology. 'We are working in a field where there has been little significant technological innovation in 120 years,' observed one industry representative.²⁹ It is therefore not

surprising that the transition to the next generation of firearms technology is taking much longer than comparable developments in other sectors, in which technological change is constant and rapid.³⁰

The limited selection of firearms currently fitted with ECSMs may also help to explain the low demand. Armatix's iP1 pistol is currently available only in .22 calibre, which few police forces use. Similarly, Kodiak Industry's Intelligun system fits only 1911 model handguns. Both companies are reportedly attempting to expand their product lines, which may make their ECSM-equipped firearms more attractive, although they will still be competing with time-tested brands that have large, loyal followings among law-enforcement agencies.

Finally, the effect of new technologies on the availability and usefulness of illicit small arms is limited by the massive number of illicit weapons already circulating worldwide—few if any of which are equipped with ECSMs, engraved with microstamps, or logged in digitized inventory-management systems. Given the inherent limitations of weapons-recovery strategies and the long lifespan of many small arms, these weapons will continue to be accessible to criminals for many decades.

Conclusion

New and under-used technologies for marking, securing, and tracking small arms and light weapons have the potential to reduce theft, loss, and diversion, and to reduce the utility of any weapons that are lost, stolen or diverted. To date, however, constraints relating to cost, budget, national infrastructure, and reliability have limited the uptake of these technologies. Many of these constraints are particularly pronounced in poorer countries, where small budgets and rudimentary or non-existent IT infrastructure limit the extent and pace at which new technologies can be deployed by security forces and other users.

Yet even the best-funded and most technologically capable government agencies fail to effectively secure all of their weapons at all times. An audit of firearm controls at 18 US federal law-enforcement agencies revealed a substantial number of cases of improper storage, delays in reporting lost and

stolen weapons, and inaccurate inventory control. According to the auditors, improper storage contributed to nearly three-quarters of the 243 firearms lost or stolen at two of the agencies from 2006 to 2008. Some of these weapons were later recovered from criminals and gang members (US DHS IG, 2010, pp. 6, 10).³¹ This example illustrates the inherent limitations of technology for controlling small arms, and the need for constant vigilance of marking, tracing, and PSSM practices in all countries, even those with robust IT infrastructure and access to the latest technology. ■

Endnotes

- 1 Full name: United Nations Programme of Action to Prevent, Combat and Eradicate the Illicit Trade in Small Arms and Light Weapons in All Its Aspects ('Programme of Action'). See UNGA (2001).
- 2 This chapter uses the definition of 'tracing' employed in the International Tracing Instrument: 'the systematic tracking of illicit small arms and light weapons found or seized on the territory of a State from the point of manufacture or the point of importation through the lines of supply to the point at which they became illicit' (UNGA, 2005, para. 5).
- 3 Full name: International Instrument to Enable States to Identify and Trace, in a Timely and Reliable Manner, Illicit Small Arms and Light Weapons ('International Tracing Instrument'). See UNGA (2005).
- 4 Author correspondence with relevant official, October 2014.
- 5 Author interviews with industry representatives, 1 and 15 May 2014.
- 6 Author telephone interviews with industry representatives, 1 and 15 May 2014.
- 7 Author telephone interview with industry representative, 15 May 2014.
- 8 Author telephone interviews with industry representatives, 1 and 15 May 2014.
- 9 A data matrix code is a 'two-dimensional array of square or round cells arranged in contiguous rows and columns. It is a binary code in which the dark data cells are given a value of "1" and the light cells a value of "0." The data cells are read from left to right, top to bottom' (Cook and Bruno, 2008, p. 276).
- 10 Author telephone interview with industry representative, 1 May 2014. According to the representative, the advantage of the code over a serial number is that it is unique. Whereas the same serial number is sometimes assigned to different firearms by different manufacturers or to a different firearm model by the same manufacturer, no other weapon bears the 12-digit code of the Industrial Fingerprint.
- 11 Telephone interview with industry representative, 1 May 2014. See also Traceability Solutions (n.d.a; n.d.b).
- 12 Currently, Baselock is compatible only with handguns. Armatix offers a rack system for long guns called Gun-rack HS and a stand-alone mechatronic safety mechanism called Quicklock (Armatix, n.d.a; n.d.b).

- 13 See, for example, Barska (n.d.) and GunVault (n.d.).
- 14 See, for example, Sports South LLC (n.d.).
- 15 See, for example, Sentinel (2014).
- 16 Quicklock consists of a blocking device and a digital key. The blocking device is inserted into the cartridge chamber, which locks in place. To release the device, the operator uses the digital key to enter a PIN code or scan their fingerprint. According to the manufacturer, 'blocking devices are available for all calibers conventionally available on the market' (Armatix, n.d.c.).
- 17 See UNGA (2014, p. 6) and Persi Paoli (2011).
- 18 See, for example, Government of Canada (2012).
- 19 These technologies and the weapons into which they are incorporated are also referred to as 'personalized firearms', 'technical-use controls', and 'user-authorized firearms' (Greene, 2013, pp. 7–8).
- 20 In this context, the 'false positive rate' is the rate at which a given ECSM fails to prevent use of the weapon by an unauthorized user. The New Jersey Institute of Technology reported that its prototype ECSM, for example, is 'set to have ... a false positive rate of 10 per cent' (Gobinet, 2013, p. 39).
- 21 Analysts have highlighted several additional technological approaches to reducing unauthorized use. These include the installation of cameras and audio recorders on firearms (Ashkenazi, 2013).
- 22 These items include the M-2000 shotgun developed by iGun Technology Corporation, the iP1 pistol made by Armatix GmbH, and the Intelligun fingerprint-locking system for installation on 1911-style 9 mm pistols (Intelligun, 2013).
- 23 Author correspondence with industry official, 4 June 2014.
- 24 In an interview with United Press International, the executive director of the National Association of Police Organizations warned that 'it would only be a matter of time before criminals would be willing to pay big bucks for breach technology' (Haubursin, 2014).
- 25 Author telephone interview with industry representative, 14 May 2014. (See also Gobinet, 2013, p. 9.)
- 26 Replacement components are readily available online, either through the black market (see US ICE (2010); US District Court Western District of Washington (2013); US Attorney's Office Southern District of Florida (2014)) or in some countries through legal, largely unregulated, private sales.
- 27 Chumbley et al. studied the microstamped identifier on ten different types of ammunition fired from three brands of firearms. They found that 'readable microstamping was achieved on most of the cartridge cases' and concluded that microstamping is a 'viable method for providing rapid identification of a firearm in many cases' (2012, pp. 147, 155). For detailed data on the transfer of identifiers by weapon and ammunition type, see Chumbley et al. (2012, pp. 150–53).
- 28 Paragraph C.2C:58-2.3b reads: 'For the purposes of this section, personalized handguns shall be deemed to be available for retail sales purposes if at least one manufacturer has delivered at least one production model of a personalized handgun to a registered or licensed wholesale or retail dealer in New Jersey or any other state' (State of New Jersey, 2002, c.130).

- 29 Author telephone interview with industry representative, 14 May 2014.
- 30 Author telephone interview with industry representative, 14 May 2014.
- 31 Such problems are not unique to US security agencies, but because the US government is more transparent than other governments, problems with its PSSM practices are better documented.

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Occasional Papers

- 1 *Re-Armament in Sierra Leone: One Year after the Lomé Peace Agreement*, by Eric Berman, December 2000
- 2 *Removing Small Arms from Society: A Review of Weapons Collection and Destruction Programmes*, by Sami Faltas, Glenn McDonald, and Camilla Waszink, July 2001
- 3 *Legal Controls on Small Arms and Light Weapons in Southeast Asia*, by Katherine Kramer (with Nonviolence International Southeast Asia), July 2001
- 4 *Shining a Light on Small Arms Exports: The Record of State Transparency*, by Maria Haug, Martin Langvandslien, Lora Lumpe, and Nic Marsh (with NISAT), January 2002
- 5 *Stray Bullets: The Impact of Small Arms Misuse in Central America*, by William Godnick, with Robert Muggah and Camilla Waszink, November 2002
- 6 *Politics from the Barrel of a Gun: Small Arms Proliferation and Conflict in the Republic of Georgia*, by Spyros Demetriou, November 2002
- 7 *Making Global Public Policy: The Case of Small Arms and Light Weapons*, by Edward Laurance and Rachel Stohl, December 2002
- 8 *Small Arms in the Pacific*, by Philip Alpers and Conor Twyford, March 2003
- 9 *Demand, Stockpiles, and Social Controls: Small Arms in Yemen*, by Derek B. Miller, May 2003
- 10 *Beyond the Kalashnikov: Small Arms Production, Exports, and Stockpiles in the Russian Federation*, by Maxim Pyadushkin, with Maria Haug and Anna Matveeva, August 2003
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- 12 *Small Arms in Kyrgyzstan: Post-revolutionary Proliferation*, by S. Neil MacFarlane and Stina Torjesen, March 2007, ISBN 2-8288-0076-8, also in Kyrgyz and Russian (first printed as *Kyrgyzstan: A Small Arms Anomaly in Central Asia?*, by S. Neil MacFarlane and Stina Torjesen, February 2004)
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- 21 *Crisis in Karamoja: Armed Violence and the Failure of Disarmament in Uganda's Most Deprived Region*, by James Bevan, June 2008, ISBN 2-8288-0094-6
- 22 *Blowback: Kenya's Illicit Ammunition Problem in Turkana North District*, by James Bevan, June 2008, ISBN 2-8288-0098-0
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