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Security scenarios: 3D printed firearms

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Abstract

The aim of this study was to determine possible future scenarios if 3D printed firearms were to be manufactured in society. These scenarios provide a closer examination of the factors influencing the use of this relatively new method of firearms production. We reviewed the factors in 3D printed firearms that are relevant to various security authorities. Scenario analysis enables the examination of problem-solving for this multi-dimensional, multi-layered and multi-scale phenomenon. The topic was approached from a systemic perspective based on complexity thinking. The scenario-creation method employed five forecasting techniques applicable to the Playbook for Strategic Foresight and Innovation (Carleton, 2013). A context map created the basis for factor analysis, generational arcs, white spots and expert panel. The scenarios were developed into a structural format, allowing for the description of coherent entities. Upon analysing the scenarios, it was found that the ease of manufacturing 3D printed firearms could lead to a rapid increase in their numbers, potentially resulting in decreased internal and external security. The networking of manufacturers could also enable the production of weapons for individuals who previously did not have access to firearms. On the other hand, 3D printed firearms could open up new legal uses and possibilities.

Keywords

additive manufacturing, scenarios, 3D printed firearms, security forecasting

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Introduction

In June 2021, in Finland, Finnish customs uncovered a firearms factory where nine printers had printed FGC-9-gun parts (Eromäki, 2021). In October 2022, police in Britain discovered a large 3D printing factory (Vallance, 2022). Spanish police uncovered a firearms factory in Tenerife in September 2020 (Churm, 2021; Keeley, 2021). In Sweden, 3D printed firearms have been found on an annual basis since 2013 (Radlovacki, 2022). According to the European Police Agency (European Union Agency for Law Enforcement Cooperation [Europol], 2022), the proliferation of 3D printed firearms is currently a threat and is likely to continue to be so in the future.

With the development of additive manufacturing (AM) technology and materials, the potential of the method for the production of usable firearms has increased (Duquet and Auweele, 2021, pp. 138–140). The method enables the manufacture of firearms without specific gunsmith tools or previous experience (CTRL+PEW, 2022).

Manufacturing firearms with this relatively new manufacturing method can have an effect on various security authorities, such as military, police, border guards, customs, and security services. Europol (2022) considers printed firearms a threat, as authorities in various countries have reported the danger of 3D printed firearms. On the other hand, this technology can provide 3D printed firearms for legitimate and/or use in special circumstances by the authorities (Sensiba, 2021). In light of these findings, it could be argued that 3D printed firearms pose a threat to both law enforcement agencies and the safety of the general public (Daly, *et al.*, 2021, p. 50).

At the International Conference on 3D Printed Firearms in 2022, Europol (2022) defined three main conclusions. First, it is crucial to identify the development of 3D printed firearms through collaboration between the authorities and the private sector. Second, there is a need to maintain an international expert network focused on 3D printed firearms. Finally, success lies in sharing common information on a global scale.

While the approach taken by different authorities may vary, the effects on security-related factors are usually closely related. A comprehensive cooperation between the authorities enables the examination of new phenomena, preventing them and minimising their effects (Organization for Security and Co-operation in Europe [OSCE], 1994). Different countries have different mechanisms for such cooperation. These mechanisms create a society-wide structure for safety. On the one hand, it enables the sharing of safety responsibilities, and on the other hand, it causes the complexity of safety management. Previous research has indicated that threats in any particular area of total security have knock-on effects in other areas (Lonka *et al.*, 2020, pp. 17–18).

The main material for this research was collected in Finland, which serves as an example of one European Union (EU) country attempting to cope with this emerging phenomenon. Finland is a good example because gun ownership is prevalent—32.4 per 100 inhabitants (Karp, 2018)—and cases of illegal 3D printed firearms have been relatively high. Although the number of privately owned weapons in Finland is substantial, it should be noted that Finnish and EU legislation (Directive 2021/555, European Union [EU], 2021) differs greatly from the US gun legislation. In the United States, the Second Amendment guarantees citizens the right to own arms, while in European countries, the right to own guns requires a permit.

The international "TARGET" research project, funded by the EU in 2021, investigated the effects of the arms trade on gun violence in the EU. The project identified two main challenges in the future: (1) The use of 3D printing to make firearms, and (2) the trade of firearms on the Internet. Such activities have an attraction for individuals who aim to purchase firearms but do not have connections to existing criminal networks (Duquet and Auweele, 2021, p.16).

One of the key motivators for this research has been the illegal 3D printed firearms discovered in Finland. The realisation that almost anyone can make a functioning firearm with this new manufacturing technology, one that works, has brought an understanding that the phenomenon must be better understood in order to evaluate its effects. A primary goal of the security authorities is to prevent the expansion of the use of 3D printed firearms and to minimise their harmful effects. As the Europol (2022) conference report shows, the phenomenon has been recognised and European security authorities have decided to initiate its findings. The effects of weapons proliferation are not limited to security issues. Therefore, a comprehensive review of the topic is important.

Previous research has examined the use of 3D printed firearms from a legal perspective (Freilich and LaFree, 2015, pp.1-8; Jacobs and Haberman, 2017, pp. 129–147; Talbot and Skaggs, 2020, pp. 98–104; Thierer and Marcus, 2016, pp. 805–864; Tran, 2015, pp. 505–520) from the point of view of the society (Daly *et al.*, 2021, pp. 37–51; Duquet and Auweele, 2021, pp.112–121; Vallance, 2022; Walther, 2015, pp. 1435–1445) and from a technological perspective (Black *et al.*, 2017, pp. 26–32). These studies have considered the problems related to 3D printed firearms and the threat they can pose. The studies have also addressed the factors that lead to proliferation of 3D printed weapons. The previous study did not deal with the wider common perspective of the security authorities on the issue and therefore up to date data is not available. This research is part of a larger study, the purpose of which is to look at the issue, especially from the perspective of the security authorities.

The aim of this study was to improve the authorities' understanding of the effects of additively manufactured firearms. In it, we focus on what factors related to 3D printed firearms affect their possible development paths. Based on this research, certain inferences can be made about groups using printed firearms, their motivations, the effect of technology on the development of the phenomenon, and the effects of the actions of the authorities on the number of weapons.

With the assistance of the main results (scenarios), the understanding of this new phenomenon by security authorities can be improved and a platform can be established for decision makers to deepen their assessment of the factors according to each authority's specific needs. This is crucial in terms of societal safety, the functioning of security authorities, and the anticipation of threats posed by the phenomenon. Building on the research findings, legislation can be revised to thwart illicit manufacturing, distribution, and use of 3D printed weapons.

Additive Manufacturing

Additive manufacturing is cited as a new era of manufacturing (Berman, 2012, p. 161). AM is "a process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies" (ISO/ASTM, Mechanical Engineering and Metals Industry Standardization in Finland [METSTA], 2021, p. 1). The main difference between AM and the so-called traditional manufacturing methods is that AM requires a digital computer-aided design (CAD) model, that is, the 3D model mentioned in the definition. This 3D model serves as the basis for building the parts with AM techniques (Paolini *et al.*, 2019, pp. 6–7). In addition to the 3D model, a 3D printer is needed to convert digital model data into a physical part. The material used in the 3D printer determines the material properties of the printed parts (Hu and Mahadevan, 2017, p. 135).

Additive manufacturing is not a single manufacturing method but covers seven different main categories, under which there are more than thirty different methods and techniques (Prakash *et al.*, 2018, p. 3877). The main categories are as follows: Vat photopolymerisation, material extrusion, powder bed fusion, sheet lamination, material jetting, binder jetting, and direct energy deposition (METSTA, 2021, pp. 2–3). The methods under these main categories have their own special features and, therefore, different methods are suitable for different purposes (Ngo *et al.*, 2018, p. 176).

Additive manufacturing enables the production of different parts with the same 3D printer (Gibson *et al.*, 2021, p. 9). Some 3D printers can produce several parts at the same time (Lu *et al.*, 2015, p. 87). In addition, one of the advantages of AM over traditional manufacturing methods is its relative speed (Holmström *et al.*, 2010, p. 688; Khajavi *et al.*, 2014, p. 1183), manufacturing directly to the needs of the user (Ituarte *et al.*, 2017, pp. 46–47), manufacturing almost without geometric restrictions (Holmström *et al.*, 2010, p. 689), availability and modifiability of 3D models and manufacturing (Ituarte *et al.*, 2017, p. 56). These factors make AM attractive to the manufacturers of firearms.

Additive manufacturing has been typically used in prototyping, developing new applications, tools, maintenance, and repair (Gibson *et al.*, 2021, pp. 8, 9, 42, 288, Stavropoulos, 2023, p. 1). Although AM is suitable for the production of different items, there are general limitations that affect the printing of firearms. Perhaps the biggest limitations are related to the layers formed by the manufacturing equipment and printing material. The limitations of printing materials and manufacturing equipment affect the method and material that is chosen. Different parts of the firearm require different properties, especially in 3D printing of firearms (Heard, 2011, pp. 10–11). Therefore, the combination of materials and machines produces the final characteristics of 3D printed parts (Gibson *et al.*, 2021, p. 61).

In addition to technical limitations, the use of AM technology has limitations regarding factors related to its production. Industrial grade AM equipment is relatively expensive (Pîrjan and Petroşanu, 2013, p. 364). The CAD models used in printing are restricted by intellectual property laws (Ballardini *et al.*, 2018, p. 959). The choice and availability of the materials used can limit the use of AM.

There are three types of 3D printed firearms and 3D printed licensed parts to firearms. The first group includes fully 3D printed (F3DP) firearms. These firearms almost all consist of 3D printed parts, including parts for high pressure and parts under mechanical wear. Typically, only a few parts, for instance, the firing pin, could be non-printed. The second group includes hybrid 3D printed firearms. These firearms are partly 3D printed while some parts are made by hybrid or traditional manufacturing techniques. The third group is Parts Kit Completions or Parts Kit Conversions (PKC) (Hays *et al.*, 2020, pp. 13–15).

3D printed weapons represent two different trends. The first is weapons made by industrial companies or state actors. In this case, the printing methods and materials have been carefully selected and the factors related to their production have been optimised both economically and productively (Slowik, 2013). Another trend is weapons made by individual operators. The purpose of these operators is to produce weapons as easily, inexpensively and in such a way that information about their manufacture is not created for the authorities. In this case, the choice of materials and technologies or the safety of the potential end user in the social environment is often not the most important thing (Paoli *et al.*, 2017, pp. 34–35).

3D printed firearms

In the United States, there were sixteen mass shootings in 15 different states in 2012. The last shooting of the year, in Newtown, CT, on December 14, 2012, killed 27 people (20 children, 6 adults and the shooter) (Ray, 2023). As a result of these shootings, US President Barack Obama announced that he would do everything he could to stop the shootings. He published a 23-point programme to curb the use of weapons, for example, use of large magazines (Curtis, 2013).

In response to restrictions, a people's movement emerged, advocating for the liberalisation of the manufacture, acquisition and use of weapons (Curtis, 2013). Wilson (2017, p. 42), a 25-year-old college student at the time, rebelled against gun laws, believing that 3D printing could revolutionise firearm production. His objective was to freely distribute the parts of the weapons he designed on the Internet. As stated previously, the starting point of the US gun laws is that everyone has the right to own a gun. However, regarding the manufacture of weapons, it was unclear whether printing is allowed to manufacture weapons. A legal debate began about the legality of printing weapons. 3D printing companies were not prepared—so they had no means of limiting production to objects that could harm someone (Mattise, 2018). On August 24, 2022, the federal "Frame or Receiver" rule went into effect in the United States, banning 3D printed firearms and treating them like any other firearm under the law (Bureau of Alcohol, Tobacco, Firearms, and Explosives [ATF], 2021 [Proposed rule of 27 CFR parts 447, 478, and 479 of 21 May 2021]). European legislation has not changed, but it should be noted that the main source of 3D printed weapons is in the United States (CTRL+PEW, 2022).

The first 3D printed weapon that was widely known to the public was the "Liberator" developed by Wilson (2017, p. 157) in May 2013. He designed a 3D printed weapon invisible to a metal detector. It can be said that the digital revolution in the manufacture of 3D printing utility weapons had begun, achieving one of its major but worrying milestones. Since 2013, various 3D printable gun models (see Table 1) have been published and are freely available on the Internet and as development projects of different organisations (Hays *et al.*, 2020, p. 12).

In March 2020, the Deterrence Dispensed group released 3D models of a printable self-loading submachine gun on the Internet. With 3D models, the group had drawn up detailed manufacturing instructions for printable parts. The purpose of the group was to make the most efficient and easy-to-manufacture homemade semi-automatic weapon available to people with limited weapons manufacturing skills and equipment (CTRL+PEW, 2022). This 3D gun model has spread around the world (DEFCAD, 2021) and is designed to produce a usable weapon. In June 2021, in Finland, the customs authority discovered a weapons factory where nine printers were used to print FGC-9 gun parts (Kerkelä, 2021).

In Finland, cases of 3D printed firearms have been revealed annually. Only one of them has brought a conviction in the district court. In it, the author had produced ten firearms and their parts with a 3D printer. The court estimated that the price of one gun had

Table 1. Collection of various 3D printed guns (CTRL+PEW, 2022; Hays *et al*., 2020, p.12; Slowik, 2013; Wilson, 2017, p. 72).

Gun model/part	Designer	Model	3D printed parts	Printing time	Material	Year
Liberator	Cody Wilson	Pistol	14	Approx. 20 h	ABS	2013
AR15 lower receiver	Cody Wilson	Part of AR-15 semi-automatic rifle	1	Approx. 9 h	ABS	2013
1911 DMLS 9 mm	Solid Concepts Inc	9-mm pistol	33	Approx. 34 h	Stainless steel, Inconel 625, PA12	2013
Glock body	Deterrence Dispensed	Glock 9-mm pistol body	1	Approx. 11 h	ABS	2016
Rapid Additively Manufactured Ballistics Ordnance (RAMBO)	The Armament Research, Development, and Engineering Center (ARDEC)	40-mm grenade launcher pistol	30–40	Approx. 48 h	4340 steel, aluminum, ABS, PL12	2016
FGC-9	Jacob D/Deterrence Dispensed	9-mm submachine gun	17	For all parts, approx. 90 h	PLA+	2020

been €1,800 when the author sold them. The perpetrator was sentenced to 1 year and 4 months in prison (Pirkanmaan Käräjäoikeus, 2023, pp. 2–3). Finnish legislation regarding the case is lighter than the reference case from Great Britain, where the perpetrator had printed two firearms in his wardrobe and received 5 years in prison (Sky News, 2023).

These two mentioned cases in courts and almost all other revealed cases have had an ideological starting point and/or firearms have been used to commit crimes (Pirkanmaan Käräjäoikeus, 2023, pp. 12–13; Rimpiläinen, 2023). 3D printed firearms manufacturers have made the firearms either for themselves to use them in direct criminal activity or to get financial benefit from their sale.

However, it should be remembered that 3D printed firearms can also have legal uses. Hunting and various forms of gun and shooting hobbies could use 3D printed guns for their special needs. The benefits of this new manufacturing method could be used by security authorities or other official groups that legally use weapons (Sensiba, 2021).

Complexity as a challenge for security authorities

Firearms manufactured through AM present challenges to security operations and organisations at various levels. Illegal weapons have been a longstanding concern for security authorities for decades. However, the changes brought about by this new digital manufacturing method are intricate. The evolving array of conceptual and computational tools allows for novel approaches to modelling nonlinear interactions within and between organisations. Complex adaptive system models genuinely offer a fresh perspective on simplifying complexity (Anderson, 1999, p. 220).

Potential shifts in the networks where legal and illegal weapons have traditionally been used necessitate a comprehensive grasp of the subject. This entails striking a balance between threats and opportunities. Concurrently, comprehension must be intertwined with the assessment of escalating threats and opportunities. This underscores the complexity and multifaceted nature of the issue (Byrne, 1998, p. 2).

Complexity thinking can help better understand the significance of harmful factors and focus on minimising the harm they cause while continuously improving the overall situation. In this study, complexity thinking is discussed as one remarkable background theory. In recent decades, "complexity" has guided work on several social sciences. There are different schools of thought on complexity thinking and Byrne (1998, pp. 213–252), among others, has used these ideas in many ways, from health disparities to the organisation of large companies.

Complexity is often described as the interweaving of many cross-interactions, where all factors can affect everything related to the phenomenon and they can interact with one another in some way (Khan *et al.*, 2018, p. 6). The law of conservation of complexity, also known as Tesler's Law, or the Waterbed Theory, is an adage in human–computer interaction, stating that every application has an inherent amount of complexity that cannot be removed or hidden. Instead, it must be dealt with, either in product development or in user interaction (Yablonski, 2020, p. 87). Complexity also refers to the targeting of effects and the variation in their intensity over time.

Complexity thinking, or rather complexity theory, has been studied and developed recently in different parts of the world (Larsen-Freeman, 2017, pp. 12–13). Interest in complexity thinking arises from the layered nature of problems. The interaction between these layers affects the identification and handling of security problems, and the impact of individual legislation (Walton, 2014, p. 123). For example, in the case of 3D printing regulation and control, restrictive measures cannot be extended to all layers of the society without harming legal activity. Complexity theory has attracted the attention of the scientific community to such an extent that its proponents consider it to be the dominant scientific trend. Geographers and environmental, human, and regional planners have applied complexity theory to topics ranging from cultural transition and economic growth to river braiding (Manson, 2001, p. 405).

Harmful complexity in an organisation is different from risk management. There is no universal risk management because every person in a social situation interacts with others in a unique way based on their own experience. Generalisation and simplification are difficult to do. On the other hand, both should be avoided. This problem requires complexity thinking to analyse it. According to Randall (2011, p. 203), the precautionary principle has been considered simplistically, and a rational approach to risk-prone decision-making was based on well-defined gambles.

In society, the activities of different security actors are constantly interacting with the environment, influencing one another in turn (Emblemsvåg, 2020, p. 49). The entanglement and the impact on other factors emphasise the dynamic and complex structure of the whole of the society and its components, where different levels and parts are related to one another through their dependencies. Intertwining should be evaluated in a multidisciplinary manner and taking the systemic approach. One must consider different dimensions of the organisation and the surrounding society and their effects on one another. Security is affected by several dynamic variables, whose identification and assessment of their impacts is very difficult (Hanén, 2020, pp. 281–282).

The complex relationship between 3D printed weapons and security authorities brings about a new form of phenomenon. This study looks at this as comprehensively as possible. In comprehending comprehensive security, the aim is to avoid reductionism and try to identify possible weak signals. The study of the entanglement of comprehensive security allows attention to be paid to the elements that produce harmful emergence and the relationships that result from them (Puustinen and Jalonen, 2020, p. 32).

Mowles (2015, p. 24) uses insights from complexity sciences, process sociology, and pragmatic philosophy and directly addresses some of the most important contradictions in organisational life that relate to innovation, cultural change, conflicts, and leadership (Byrne, 1998, p. 2). According to Suh (2005, p. 300), assessing uncertainty understands what we want to know or achieve with functional requirements. A measure of uncertainty is what we want to know or in achieving a functional requirement.

Methods

The most important method of this research is forecasting the future. Foresight methodologies include different ways of predicting future developments. These methods can be divided on a time and data basis (da Fonseca *et al.*, 2004, pp. 75–77). War Game Simulations (North Atlantic Treaty Organization [NATO], 2013, pp. 2–12), forecasts, horizon scanning, roadmaps, back casting, weak signals and wild cards, scenarios and Delphi method are the most common techniques in the future research. Where war game simulations aim to provide short-term information partly qualitatively and partly quantitatively, the scenario method aims to produce longer-term qualitative information (Jacobsen and Hirvensalo, 2017).

This study laid the groundwork for using the Delphi method as part of a larger study of 3D printed firearms. The Delphi method required the use of scenarios when describing future claims to specialists (Linstone and Turoff, 2002, pp. 3 and 10). In a larger study, based on this research, we gather a specialist group from different authorities and ask for their opinions and reasoning to support their claims anonymously about 3D printed firearms. Using the Delphi method, the impact of 3D printed firearms is investigated from the perspective of security authorities working with weapons—especially soldiers, police and border authorities.

The scenario method is used very widely, especially in defence and security planning. It enables the examination of possible development paths in the future and limits the number of possible variations so that operations can be developed proportionately. (European Foresight Platform (EFP), 2014). It is characteristic of the scenario method that the information studied has an effect in the longer term (Jacobsen and Hirvensalo, 2017). Using this method, factors can be created that can influence strategic measures, such as legislation, creating a security strategy, and updating threat models.

We collected the techniques of the scenario method that are best suited for this study. For the detailed use of the techniques, we used the Strategic Foresight and Innovation Playbook (Carleton, 2013, pp.1–256) where appropriate. At first, we mapped the situation of 3D printed firearms in the world. The research was carried out with a literature review. Then we made a separate review of 3D printed firearms and the criminal processes that are currently underway in Finland. In Finland, the weapons legislation does not allow the manufacture of 3D printed weapons. The situation in the rest of Europe is very similar. The limitations of the EU legislation and Finnish national legislation were chosen as the environment for examining the scenarios.

With regard to 3D printed firearms, the known facts were analysed and a context map (Carleton *et al.*, 2013, pp. 61–66) was created to classify the key factors. With the help of the context map, it was possible to identify the most relevant factors related to the scenarios. The examined factors formed the framework of the scenarios, which was followed in the description of all scenarios and enabled the harmonisation of terms between the scenarios.

After identifying the factors to be considered, generational arcs (Carleton *et al.*, 2013, pp. 94–99) were created. In this study, the population was considered to be 3D printed firearms. The change in these populations was examined using change arcs. Studying the population of 3D printed firearms is essential for examining the possibilities of the phenomenon. The spread of firearms, the ease of their manufacture, and the improvement of quality can cause substantial changes in legislation and thus in the operating environment of the authorities. In situations of population change, it is necessary to look at how the population changes over time and what kind of effects different actions can have on the population. In the scenarios, it is essential to identify different options for the populations.

In the third stage, the White Spots method (Carleton *et al.*, 2013, pp.127–133) was used to build the case, where alternative "hidden" use cases were searched for 3D printed firearms. With the help of these hidden use cases, it was possible to examine whether someone or some user groups were overlooked in the study. This method also examined possible other alternative scenario flows. In this case, the purpose was to also examine the phenomenon from the perspective of the users who had been created in the context phase.

In the fourth step, other possible perspectives and additional scenarios were examined by presenting the created scenarios to a peer group of specialists. The peer group consisted of four specialists with a different technology-related background. One specialist works as a technology forecasting coordinator in a big Finnish government authority. He has done doctorate and Master of Science in engineering. One of the specialists has previously worked with technology and safety forecasting. He has a post-graduate degree in military sciences and a master's degree in artificial intelligence (AI). One of the specialists works with safety–critical systems. His research work examines the use of new technology in a military environment. He has a master.s degree in technology and in military sciences. One of the specialists works with robotics, 3D printing and automation. He is a master of technology in robotics and a PhD candidate in two different PhD programmes.

The task of the group was to assess how realistic the scenarios were and whether the members of the peer group agree with the content of the presented scenarios. The peer group was presented with one scenario at a time and asked to evaluate on a seven-point scale whether the scenario was one that the evaluator agreed with and whether he/she possibly had a new perspective on it (Carleton *et al.*, 2013, pp. 168–172). If the evaluator had a new perspective on the scenario, the observations were written down and their content was evaluated by the researchers in relation to the results of the previous stages, the operating environment of the study, and the choices. In the last, fifth step, new observations and perspectives were included in the scenario if it produced new information for the scenario.

Results

Based on the context analysis, three key factors affecting 3D printed weapons were identified: (1) AM (Daly *et al.*, 2021, p. 50) and related technologies and materials (Shi et al., 2021, p. 2), (2) firearms manufacturers and users (Veilleux-Lepage, 2021) and the network formed by them (Basra, 2022) and the benefits of making weapons (Pirkanmaan Käräjäoikeus, 2023, p. 17) and (3) Safety (Europol, 2022) and the primary means of regulating safety legislation (Jacobs and Haberman, 2017, p. 131; Tran, 2015, p. 512). The entities identified based on the context analysis were broken down into further sub-areas to enable a more detailed examination. The factors are shown in Figure 1.

The generation arcs were illustrated by the population principle, where the number of firearms is considered in relation to time. Real time was not used in the study but the time axis describes the progression of time. Arcs in the first scenario (see Figure 2) were based on the number of 3D printed firearm cases reported in Finland (Churm, 2021; Eromäki, 2021; Europol, 2022; Kerkelä, 2021; Radlovacki, 2022). The second scenario was made for the linear option (see Figure 3). The linear option is typical, as it offers the possibility to contemplate phenomena from the capability perspective (Mitra *et al.*, 2019, p. 5). Linear development also makes it possible to examine the key factors of the phenomenon without fluctuations in the population. The third scenario was achieved by identifying the future progression of the technology using the S-curve principle (see Figure 4). This principle is based on the notion that a new evolutionary innovation will be technically bigger and/or better than the previous versions (Foster, 1986, p. 100). In the last scenario, it was recognised that if the authorities' actions are carried out and AM technology does not develop as expected, the number of weapons will decrease. The fourth scenario was created for this unlikely but possible option (see Figure 5).

Figure 1. Entities recognised in the context analysis.

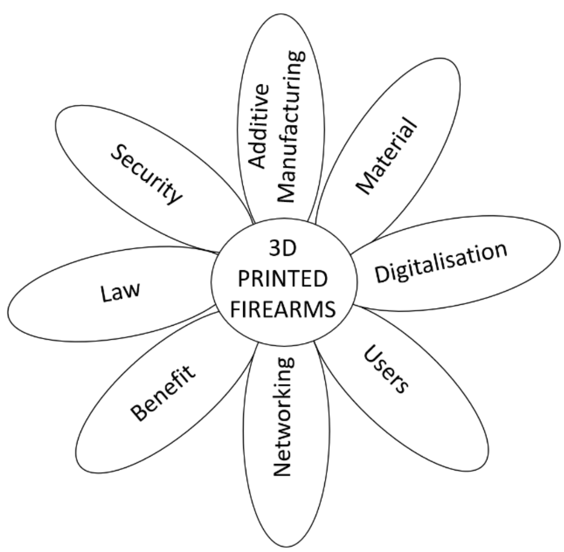


Figure 2. Scenario 1: 3D printed firearms expansion over time.

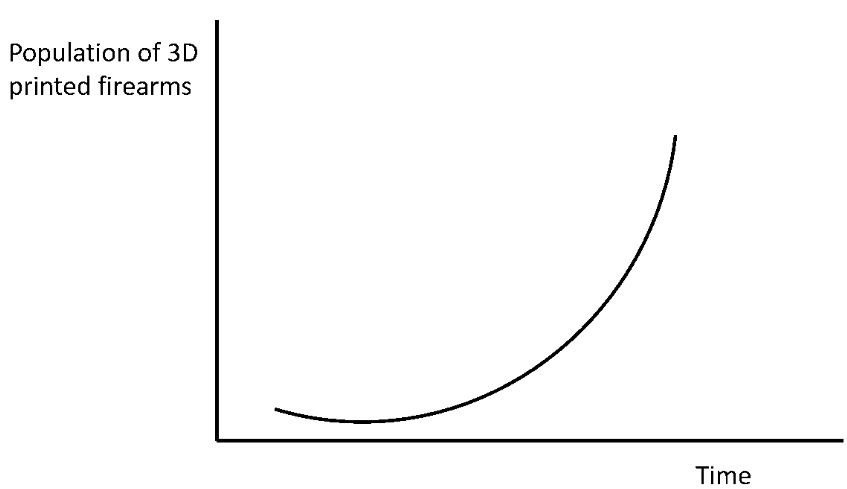


Figure 3. Scenario 2: linear expansion.

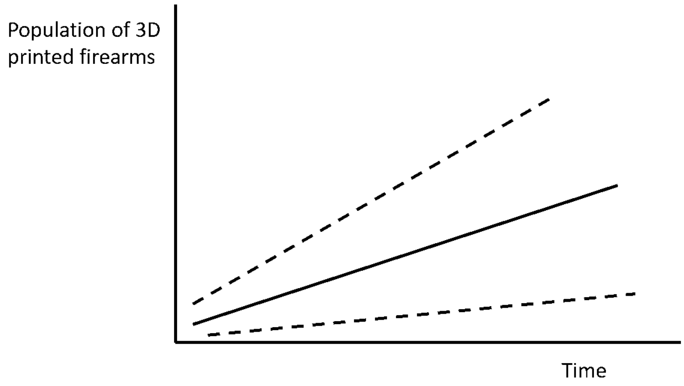


Figure 4. Scenario 3: technological.

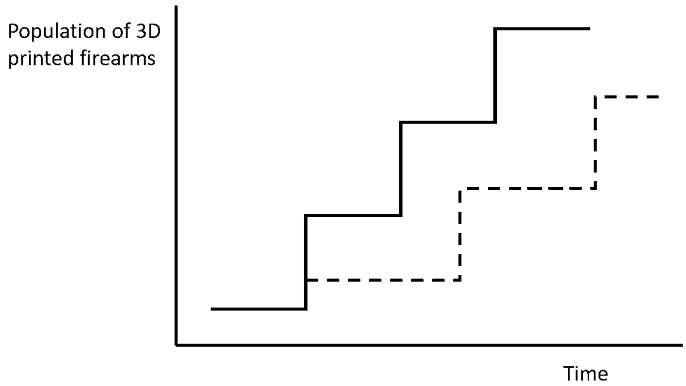
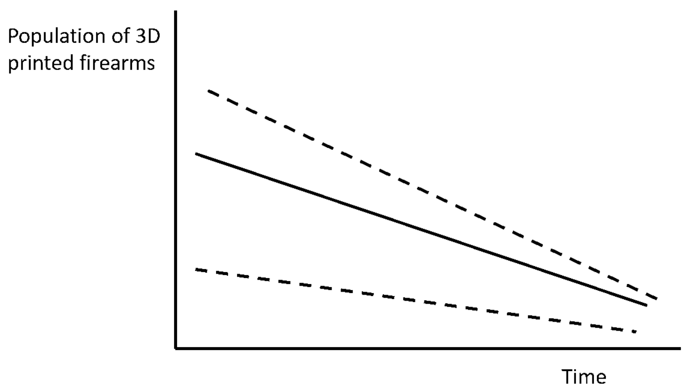


Figure 5. Scenario 4: tightening screw.



SCENARIO 1: "RAPID EXPANSION"

Additive Manufacturing

- Improvement in 3D printing technologies—better quality, quicker and easier to use.
- 3D printers are getting cheaper.

Material

- 3D printing materials are evolving. Better materials can be used in a 3D printed firearm.

Digitalisation

- Improvement in the availability of CAD models.

Table 2. Summary of the features of different factors in the scenarios.

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
Additive manufacturing	Quality, speed, price and usability	Number of 3D printers	Technological development, services	Regulation
Material	Materials are evolving	Material variation, different materials with one 3D printer	Metal materials for customers	Materials too weak
Digitalisation	Availability of CAD models is not limited	CAD model's availability increases, secure data sharing	Access to models in collected and structured database	Models are not available, too laborious to create CAD models
Users	Experimenters increase	Acceptability increases, new groups, purposes expand	Legal users, purpose-built firearms	Decrease in crime, expectations not met
Networking	International networks	Modelling ability improves	New ways of networking, distributed manufacturing, ideology	Networks are unable to produce models
Benefit	Prices remain high, risk too low	Cheaper use of 3D printing, "black market"	Faster way to get benefit	Prices decrease
Security	External security threat, internal threat (extremist)	Roadman culture, networking individuals	Crime changes, tension between gangs	Security reform
Law	Lenient sentences, lack of regulation	AM is not recognised from legal perspective	Legislation lags behind technology	Punishment, risk of being caught

Users

- Firearm users and experimenters increase.
- Users of 3D printed firearms are coming from new geographical areas.

Networking

- International networks that develop and design 3D printed weapons.
- Criminals and/or gangs create a network.

Benefit

- Illegal gun prices remain high.
- The risk between financial benefit and possible conviction is too low.

Security

- External security threat—ongoing war in the nearby area and its termination may cause technology transfer or an increase in the number of 3D printed firearms.

Law

- Lenient convictions, compared to risks.
- No regulation related to 3D printer manufacturers and/or sellers.

SCENARIO 2: "LINEAR AND PREDICTIVE"

Additive Manufacturing

- The general use of 3D printing is increasing.
- Durability, functionality and effectiveness of weapons can be demonstrated.

Material

- The material variation increases.
- Different material types with one 3D printer.

Digitalisation

- Models available freely—the authorities are unable to restrict access to models.
- Secure data sharing.

Users

- The acceptability of the use of 3D printers increases—new groups of users.
- The use of 3D firearms expands with development (e.g. precision/hobby shooting, hunting).

Networking

- Modelling ability improves.

Benefit

- The use of 3D printers becomes cheaper linearly.
- "Black market."

Security

- Roadman culture, where the related pursuit of an expensive lifestyle is achieved through criminal means.
- From criminal organisations to gangs with networking individuals.

Law

- The legislation does not consider new types of manufacturing.

SCENARIO 3: "SUSCEPTIBLE TO INFLUENCE"

Additive manufacturing

- Rapid 3D printing technology development.
- The use of outsourced services becomes possible.

Material

- Metal materials for consumers.

Digitalisation

- Access to models is limited.
- Technical means enable barriers to access to models.

Users

- Legal use is increasing.
- Purpose-built firearms.

Networking

- New ways of networking.
- Distributed manufacturing.
- The ideological group organises the network to work actively to print weapons.

Benefit

- Faster way to get benefit from 3D firearms.

Security

- Increase in tensions between gangs.
- Crime changes.

Law

- Technology develops faster than legislation.

SCENARIO 4: "TIGHTENING SCREW"

Additive manufacturing

- Regulation restricts the use of 3D printers.

Materials

- Materials are not suitable.

Digitalisation

- Models are not available.
- Too laborious to produce models and testing.

Users

- The number of users decreases with the reduction in crime.
- Do not meet with the expectations of the user.

Networking

- Networks are unable to produce models, or the use of models is blocked.

Benefit

- Prices decrease with availability.

Security

- Security reform.
- The number of security authorities is increasing.

Law

- The punishments get tougher.
- The risk of getting caught increases.

Discussion

Activities involving 3D printed firearms, among manufacturers, users and their networks, are undergoing constant change. Changes in users or their requirements can swiftly affect the production and use of 3D printed firearms. Additionally, changes in the security and political situation in the nearby countries can influence the demand for 3D printed firearms. It is conceivable that crises may lead to an increased need for weapons, or upon their resolution, illegal firearms may be relocated. External or internal threats can prompt the mobilisation of various groups and a rapidly changing level of demand for weapons. An increase in demand may manifest itself in the increased production of 3D printed firearms.

Advances in 3D printing technology and materials can, potentially, result in an escalated production of 3D printed firearms, thereby leading to a deterioration of the national security situation. With 3D printing, technological progress has enabled consumers to access materials and technology that were previously unobtainable. As AM continues to develop, 3D printed firearms may continue to improve, making the process of 3D printing them even more threatening.

Based on the previous research (Walther, 2015, pp. 1440–1445), it can be stated that after the creation of the first 3D printed gun in 2013, we have rapidly progressed to an entirely new technical and operational level in 3D printed firearms in less than a decade. On the Internet, there are numerous CAD models and manufacturing instructions for 3D printed firearms. 3D printers can be acquired inexpensively, and the materials they use are easily available. The quality of 3D printers and materials are continually improving, making 3D printing a viable option for specific groups, such as criminals and weaponised authorities obtaining firearms.

As we mentioned in the previous section, the same legislation in the United States can be applied to 3D printed firearms as applied to industrially produced weapons (ATF, 2021 [Proposed Rule of 27 CFR Parts 447, 478, and 479 of 21 May 2021]; Listek, 2022). It is easier to regulate the production of industrially manufactured weapons, and changes to their production can be enforced through official actions. In the case of 3D printed firearms, consumer control and production quality control are more challenging. Therefore, in those countries where 3D printed firearms have been included in weapons legislation, 3D printing has been considered as one manufacturing method alongside others. What makes this problematic is that Finnish or typical European gun legislation is not that liberal.

It is the opinion of experts who took part in this research that the production of 3D firearms is unlikely to decrease in the future. Consequently, the authorities would be well advised to integrate into their operations an understanding of how this new phenomenon is evolving and what types of weapon models are emerging onto the market. The authorities should be capable of identifying 3D printed firearms and preventing their illegal use.

It should be acknowledged that this study was conducted from the perspective of the authorities. The initial aim of the research was to identify factors that could influence the availability and utilisation of weapons. Therefore, this study did not focus on factors that could facilitate or influence the legal use of weapons. Additionally, the research did not concentrate on the investigative methods employed by authorities to restrict the production and use of 3D printed firearms. The significance of these investigative methods should not be underestimated. This research serves solely as the groundwork for further exploration into 3D printed firearms for law enforcement authorities.

Conclusion

The aim of this study was to discover possible development paths concerning 3D printed firearms. The study found that the most important factors affecting the number of 3D printed firearms are users, technology, and the actions of authorities. Evaluation of the identified factors and their combined effects enables the anticipation of development trends.

The study also revealed that factors related to 3D printed firearms change over time. Changes in AM technology and materials, firearms manufacturers, users, and safety considerations affect the measures influencing their production and use. Since 3D printed firearms are linked to technological advancements, predicting the speed of development becomes challenging. Despite this difficulty, it is possible to observe various types of developments and identify the effects of different factors on potential scenarios.

Possibly the most worrying scenario is Scenario 1, "Rapid Expansion." When we analyse this scenario in terms of the most crucial factors identified, it becomes evident that the likelihood of a decrease in the demand for weapons among the primary users of 3D printed firearms—criminals—is very low. The advancement of AM technology and materials has been rapid, and there are no signs of it slowing down. Consequently, the authorities have an important role in shaping the development of this scenario.

With the complex theory, we found that emergence in the security system manifests itself as the interaction of new features, factors, and actors identified in this study. Because of this interaction, measures can be taken, and potential threats can be anticipated. These measures have the potential to enhance society's safety. Despite the complexity of the phenomenon, identifying it and breaking it down into its constituent parts make it possible to exert influence at various levels. A systematic examination of the phenomenon can yield structured information regarding its impact on public safety. This review can also help identify distinct roles for different actor authorities. This paper suggests that law enforcement could be employed to monitor, track, and identify users as well as to uncover and apprehend illegal weapons manufacturers. Legislators should ensure that laws remain current. Customs and border control authorities could be tasked with identifying and preventing cross-border crime, while the armed forces should address external security threats and provide support to other authorities as needed.

Based on the scenarios developed in this research, an examination of how 3D printed firearms affect various authorities would seem to be warranted. It is conceivable that certain authorities might integrate this new manufacturing method into their own activities. Some security agencies may encounter 3D printed firearms within the scope of their regular duties. It is therefore very important for these authorities to recognise this phenomenon and be able to incorporate it into their tasks. This subject requires further research, particularly in order to provide an understanding of how different authorities perceive the phenomenon and what effects it may have on their operations.

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Data available on request from the authors.

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