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Mapping the Multi-layered Additive Manufacturing (AM) Community: Understanding the Future Landscape and Implications for National Security

Introduction

Emerging technology is moving faster than government planning and policy development can track. Emerging technology is not just evolving rapidly, but much of it is evolving outside the control – or even the understanding – of the national security community. Though most research on emerging technology focuses on the (sometimes alarming) physical characteristics of innovations, the community driving innovation remains understudied. Understanding these creators, diffusers, and users of technology will be key to successfully navigating the future environment of strategic tech.

Additive manufacturing (AM), and its implications for national security, is of particular concern. First, AM has already been identified as a potential threat to counter-proliferation efforts. By reducing the observable industrial footprint of proliferation efforts, facilitating intangible technology transfer, and reducing the necessary skill level of users, it significantly lowers barriers to entry for weapons of mass destruction (WMD) development and production by nefarious actors. Secondly, industry adoption of licit AM within the US and allied countries will undoubtedly impact their manufacturing bases. By empowering some firms and sectors, and hollowing out others, the landscape of industry – as well as its relationship to the state's national security apparatus – will change dramatically, with significant consequences for planners.

We seek to remedy this emerging lacuna in our understanding of AM thought communities. First, we seek to understand the most immediate level of impact – patents. These are AM innovations that are easiest to detect and have the most proximal impact on the national security space. Second, we seek to map the academic community that is refining and vetting the upcoming generation of AM techniques: the basic research that will result in tomorrow's innovations and applications. Third – and most ambitious – is to map the "primordial ooze" of AM thinking. This includes the online maker/hacker/hobbyist communities that are producing and proliferating the most far-reaching, notional, and sometimes fantastical ideas about AM. Many of these ideas will come to naught, but a handful may be game-changers.

These layers of analysis are explained more fully below. The scope of the work will be to build, map, and analyze these networks. The goal is to identify "who is doing what, with whom", with the intent of providing insight into how AM may shape national security today, tomorrow, and into the future.

Layer 1: Patent applications (US scope)

Rapid developments in the *application* of AM technology are largely driven by the private sector, as individuals and corporations turn theoretical insights into marketable products. Using data from the US Patent and Trademark Office (USPTO), we will build a network of AM-related patent applications in the United States, cross-referenced at both the individual and corporate level. This will let us map innovation and collaboration both by individuals (who often transition between companies) and through larger-scale joint corporate efforts. The resulting data set will allow us to identify key movers and shakers in the AM community: individuals, groups, and corporate entities that are driving technological evolution.

Layer 2: Academic research (global scope)

The academic community is responsible for many of the major *theoretic* breakthroughs in AM. These innovations may have less immediate impact on the field than patent applications and products, but their longer-term effects will dictate the scope of future innovation. We will map this layer of the AM community by building a database of (co)-authorship of academic research articles. Repositories of published research such as JSTOR will allow us to map the established network of AM knowledge and collaboration in the academic sphere. We can also draw on stores of more cutting-edge theoretical work, using repositories of working papers such as ArXiv. These data will allow us to trace back and map the emergence of the academic AM community over time, as well as the research trajectories of individuals and working groups in the AM field. Here, we can identify research groups, facilities, and individuals that are – and will be – shaping the future of AM.

Layer 3: Social communities (English-language scope)

Many of the day-to-day practitioners in AM are unlikely to either publish academic research or apply for original patents. Instead, these individuals apply existing knowledge in innovative ways, adapting AM technology for new, often unforeseen purposes. We will map this community in two steps. First, we will map the individual sub-networks that constitute the major online AM social communities – forums and message boards dedicated to aiding and connecting users of AM technology. This will let us identify important actors in these sub-networks: individuals who are highly active knowledge providers or prolific collaborators. Second, we will attempt to map the higher-level social network by building a database of users who who participate in multiple online communities. This allows

us to identify 'bridging' individuals who can easily transfer ideas and information between different AM networks. These data can be used to identify opportunities for collaboration, communication, and information-sharing between state security interests and the broader social network of AM technology.

Understanding the Value of Such Analysis

This initiative adds unique value in two ways.

First, we adopt an explicitly network-centric approach to mapping the AM community. Innovation is not an isolated phenomenon: it requires information sharing and collaborative effort within an intellectual community. By embedding the individuals, groups, and organizations driving AM innovation in their relational context, we can uncover new information about how the community as a whole is evolving and changing.

Second, our conception of the AM community is multi-layered. Our approach identifies three facets of this community: academic research, professional innovation, and social information-sharing. The overlap between these populations is significant, but nowhere near complete, and the underlying social structures and motivations of these groups can vary widely. Understanding the differences between academic, professional, and social groups can help us model and predict community behavior, and tailor more effective strategies for multi-layer engagement. These efforts can be tailored to ideas, concepts, or topics that have repercussions for specific national security needs, from nuclear weapons development to the changing manufacturing capacities of nations.

This multi-layered network analysis has three goals: *mapping*, *understanding*, and *engaging* the AM network.

Mapping the AM community
This initiative looks at the AM community as a multi-faceted, interconnected web of actors and relationships. Because of this, we can ask and answer different questions not only about specific aspects of AM (breakout innovators, emerging growth areas) but about the structure of the community as a whole. For example, much of the rhetoric surround AM emphasizes how this tech "democratizes" innovation. Network analysis can help us identity the extent to which this is true: are innovations being spread out among the community? What is the size and population of the 'core innovators' across these different layers of AM?

Understanding the AM community
What is the impact of innovation? How can we measure, track, and even simulate and predict changes in the structure and scope of the AM community as new inventions and discoveries enter the field? Effectively mapping the AM community network will allow us to better understand the cascading effects of new innovations,

and to create explanatory and predictive models that shed light on how the AM community responds to new developments.

Engaging the AM community

The United States government needs to develop strategies to effectively interface and collaborate with the AM community – as many of these communities are not amenable to interfacing with the traditional instruments of state power. However, there is no 'one size fits all' approach to doing so. Effective strategies are likely to vary both by formal role (for example, private sector developers versus academic researchers) and by functional role (mobile collaborators, solo inventors, and other archetypes of AM innovator). Network analysis of the AM community allows us to identify key actors in terms of both formal and functional roles, and to develop effective strategies that target these different types of actors for engagement.