Decision Considerations for Securing and Managing Intellectual Property within Additive Manufacturing Supply Chains

Adu-Amankwa, Kwaku; Rentizelas, Athanasios; Daly, Angela; Corney, Jonathan; Wodehouse, Andrew; Peron, Mirco

Published in:
Proceedings of the 22nd IFAC World Conference

DOI:
10.1016/j.ifacol.2023.10.304

Publication date:
2023

Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnLine 56-2 (2023) 6543–6548

Decision Considerations for Securing and Managing Intellectual Property within Additive Manufacturing Supply Chains

Kwaku Adu-Amankwa[1,*], Athanasios Rentizelas[2], Angela Daly[3], Jonathan Corney[4], Andrew Wodehouse[5], Mirco Peron[6]

[1]*Department of Design Manufacturing and Engineering Management, University of Strathclyde, United Kingdom (Tel: 0141 548 2091; e-mail: kwaku.adu-amankwa@strath.ac.uk) | *Corresponding Author*

[2]*School of Mechanical Engineering, National Technical University of Athens, Greece (e-mail: arent@mail.ntua.gr)*

[3] *Leverhulme Research Centre for Forensic Science, School of Science and Engineering, University of Dundee, United Kingdom (e-mail: adaly001@dundee.ac.uk)*

[4]*School of Engineering, University of Edinburgh, United Kingdom (e-mail: j.r.corney@ed.ac.uk)*

[5]*Department of Design, Manufacturing and Engineering Management, University of Strathclyde, United Kingdom (e-mail: andrew.wodehouse@strath.ac.uk)*

[6]*Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology, Norway (e-mail: mirco.peron@ntnu.no)*

Abstract: Intellectual property is a crucial asset that generates debates about its effects on additive manufacturing supply chains. Actors within these supply chains must adapt to navigate intellectual property issues and decisions to sustain growth. However, no consensus exists among scholars and practitioners on "whether, why, or how" to secure and manage intellectual property, which complicates decision-making. This paper presents a quantitative survey of expert opinions from management, engineering, academia, and consultancy sectors on various decision considerations for securing and managing intellectual property in additive manufacturing supply chains. The findings indicate that decision-making remains significantly complex and non-uniform; this offers insights into crucial considerations when aiming to secure or manage intellectual property as a valued and balanced asset in additive manufacturing supply chains.

Keywords: Intellectual Property, Additive Manufacturing, Supply Chain Management, Decision Consideration

1. INTRODUCTION

Supply Chains (SC) for manufacturing integrate key business functions within and across entities to cover material and informational interchanges from raw material acquisition to final customer delivery (Hugos 2018). Due to the 4th industrial revolution, SCs have adapted to incorporate technological, sectoral, and societal advancements, thus ushering in the "Smart Era of 4.0." A key disruptive technology at the core of these SC transformations is Additive Manufacturing (AM), which involves joining materials to create parts based on 3D model data (Gibson *et al.* 2021). SCs that mainly use AM are often called Additive Manufacturing Supply Chains (AMSC). AM's ability to rapidly transform product data between the cyber and physical domains makes AMSCs desirable in addressing manufacturing constraints like lead time or design complexity. Yet, AM introduces critical security challenges, including those involving Intellectual Property (IP), and these issues must be appropriately managed to ensure value does not wane within AMSCs (Chan *et al.* 2018). IP emerges as a widespread concern within AMSCs because IP entails a group of intangible assets that generate value and entitlements over human innovations (Noam 2019) yet are often misunderstood in relationship to AMSC. Within AMSCs, multiple parties inevitably exchange tangible and intangible products across cyber and physical domains from process beginnings to ends (including IP with clear ownership and unclaimed ownership), thus, making IP management complicated due to numerous risk mitigation decisions that must be taken across multiple domains within resource constraints (George *et al.* 2019).

The need to balance IP issues becomes apparent when an entity (individual, group, or institution) must deal with external parties for IP value creation, usage, or retention within AMSCs. Overzealously securing and managing IP is often criticised as counterproductive because it introduces artificial scarcity, fosters overreaching control; limits legitimate use; and makes it complex to handle across multiple domains (Weber 2001). Consequentially, overprotecting IP may negatively impact efficiency and innovation. Contrarily, securing and managing IP assets are deemed strategic needs for individuals, corporations, and governments, especially in our current era of a knowledge-driven economy (Ezell and

10.1016/j.ifacol.2023.10.304

Cory 2019). Scholars and practitioners continue investigating this area to unveil IP opportunities and barriers, thus, confirming Soares and Kauffman's (2018) findings on IP's relevance as an intangible activating asset that is instrumental within the "Smart Era of 4.0" due to its impact on the value chain. IP could account for 80% of an entity's technology transfer value within its operating business ecosystem, like how AMSCs shift value between cyber and physical domains (Villafaña-Díaz and Lezama-De La Rosa 2020).

Ironically, decision-making on IP strategies is not straightforward due to several contending considerations that come into play when settling on strategies for managing or securing IP as a multi-domain asset flowing within AMSCs. So, we describe the term "decision considerations" as high-level factors (logic, perception, experience, and effect) that influence strategic choices (action or inaction) by actors within the SC when securing and managing IP linked to AM applications. Accordingly, within the legal, security, and management literature, concerns are often raised about IP-related decision considerations, especially within AMSC contexts which trigger numerous efforts to address emerging issues. A few identified studies include Yampolskiy et al. (2014), who examined IP on existing AM outsourcing models to propose a conceptual model that looked at security decision considerations like IP violation modes and types of SC actors involved when outsourcing AM operations. Similarly, Daly (2016) explored IP on legally recognised eligible AM artefacts that may be protected to determine socio-legal decision considerations like IP protection eligibility via existing laws, implications of IP imbalances, and potential required regulatory reforms to address limitations. Comparable inferences were made by Hannibal and Knight (2018), who examined managerial dimensions regarding the physical location of AM factories and storage of AM data as a tactful decision consideration towards the value of IP in production transactions across AMSCs. Furthermore, George *et al.* (2019) outlined decision considerations about the loss of visibility over exchanges performed by handling parties (trusted or untrusted), thus leading to potential IP misappropriation. They discussed possible methods or solutions for IP security within AMSC contexts. Friedrich et al. (2022) analysed AM distributed SC infrastructure on make-or-buy decision consideration to stress the need for protecting IP within AMSC transactions via their developed framework that manifested concerns about IP violation risks via data sharing, reverse engineering, and prosumer market competitions. Finally, Adu-Amankwa et al. (2022) explored IP issues about Replacement Parts (RePt) within AMSC via quantified empirical insights into concerns levels for multiple interrelated IP, AM, SC and RePt issues to suggest guidance on management and control decision consideration that experts perceived to require priority attention.

The studies above represent efforts to understand different emerging decision considerations when strategically managing IP as a secured asset within embedded business processes of an entity operating with an AMSC. We postulate the augmented value in empirically studying decision considerations for securing and managing IP within AMSCs, especially as part of an entire strategic business process. Indeed, securing and managing IP within AMSCs presents several complexities when navigating existing business, legal, and production structures. Accordingly, this results in several decision considerations, which are often theoretically or conceptually described; but, unfortunately, not always empirically measured, captured, analysed, and understood on the extent of applicability of these options from stakeholders of the AMSC. This paper determines key decision considerations, based on their perceived relevance to practitioners and academics, associated with IP security and management when using AM within SCs. This paper's findings contribute evidence from multi-stakeholder insights that extend our understanding of IP assets within AMSCs. This paper's structure is organised as follows: *Section 2* outlines methodology; *Section 3* presents findings; *Section 4* discusses outcomes and draws some conclusions.

2. APPROACH AND METHOD

Literature was reviewed to scope decision considerations associated with AM use within a SC, mainly from IP perspectives. As advised by Boland *et al.* (2017), literature findings were discussed with a review panel (academics and practitioners) to affirm the proposed high-level classification of discovered themes being outlined to conduct the empirical study. These themes were further consolidated and clarified to arrive at 8 focal decision considerations, which are described and labelled with a two-letter mnemonic below:

- *Valued Role of Intellectual Property* (Va): this consideration entails treasured aspects about securable/secured intellectual property at the various stages of its life span.
- *Implications of Securing Intellectual Property* (Im): this consideration entails internal or external consequences that emerge from securable/secured intellectual property.
- *Mechanisms for Securing Intellectual Property* (Me): this consideration entails mediums and techniques employed to securable/secured intellectual property.
- *Parties involved in Intellectual Property Life Cycle* (Pa): this consideration entails stakeholder entities encountered in handling securable/secured intellectual property.
- *Eligibility Awareness on Securable Intellectual Property* (El): this consideration entails whether awareness exists of the types of intellectual property that are securable/secured.
- *Agents of Intellectual Property Violations* (Ag): this consideration entails ways in which securable/secured intellectual property is violated/contravened.
- *Artefact Embodiment of Intellectual Property* (Ar): this consideration entails ways in which securable/secured intellectual property is contained/realised.
- *Underlying Motives for Securing Intellectual Property* (Un): this consideration entails implicit/explicit reasons for pursuing securable/secured intellectual property.

Once ethical approval was granted, the survey questionnaire was deployed to pilot the response delivery. The goal was to

assess the extent of individual and collective relevance behind each decision consideration using empirical data from subject matter experts via a descriptive survey design (Sallis *et al.* 2021). A design issue was discovered due to the closed nature of labelled response options about the high-level abstraction of decision considerations, compared to the variety of implicit and explicit decision considerations that emerge from each respondent's background. So, the piloted sessions revealed a preference by respondents for some guidance on the decision considerations being presented to them to avoid response ambiguity errors that may arise from avoidance, guessing or misinterpretation. Therefore, the questionnaire contents were redesigned, and a researcher-guided survey delivery approach was adopted for re-piloting. This proved much more successful in comprehension reliability and validity than the previous self-administered approach (Saunders *et al.* 2019).

With the aid of the Qualtrics platform, the redeveloped questionnaire was administered to each participant via several online web meetings. The researcher-guided online delivery was deemed apt because it facilitated additional elaborations, enabled immediate answering of participants' questions, and encouraged allocating ample time for the data collection activity. Regarding participants' demographic descriptions, this study focused on participants with knowledge and experiences about at least one of the essential subject areas: AM, IP, or SC. Accordingly, a purposive sampling approach was used to recruit participants. This was done via peer referrals and online profile searching on LinkedIn to reach relevant candidates (Bryman and Bell 2019). Out of 37 invited persons, a total of 29 participants took part in this activity. Participants' roles comprised, *Consultants* (Technology), *Academic* (Professorial), *Engineers* (Research, Manufacturing and Design), and *Managers* (Executive, Strategy, Technology, Manufacturing) in ascending order.

During data collection, participants were presented with multiple response type questionnaires on decision considerations to measure relevance when seeking a means for securing IP within AMSC contexts. Each participant was presented with a randomised arrangement of the 8 focal decision considerations, supported with further explanations when needed. Based on each participant's clarified understanding, they were asked to indicate as many options as deemed applicable when securing IP for AM use within the SC (Easterby-Smith *et al.* 2015). The main question asked was:

Could you indicate which of the presented considerations you deem relevant when making decisions about securing or managing Intellectual Property, based on your viewpoint on Additive Manufacturing use in the Supply Chain?

The responses were analysed using statistical methods at both a descriptive and inferential level. The statistical correlation methods comprised tests for associations among pairs within contingency tables of the nominal variables (decision considerations), using Fisher's exact test due to violations of Chi-squared test assumptions (Agresti 2007, Rea and Parker 2014). Ultimately, to explore whether there was any conclusive relationship among variables within the response pattern (Paczkowski 2021). The hypotheses tested were:

$1H_0$: No significant relationship exists between any pair of decision consideration choices.

$1H_1$: A significant relationship exists between any pair of decision consideration choices.

$2H_0$: No significant relationship exists between participants' roles and decision consideration choices.

$2H_1$: A significant relationship exists between participants' roles and decision consideration choices.

A response pattern analysis was performed to determine which decision considerations respondents deemed relevant; then, abductive reasoning was used to derive probable meanings.

3. RESULTS AND FINDINGS

Table 1 presents participants' collated responses, where calculated percentages represent the entire respondents' group. It was observed that all 8 options were selected at least once, which validates their selection as possible decision-making considerations about IP management and security when using AM in SCs. The results also revealed that most participants were inclined towards *Me* and *Pa*. Then *Im*, *Un*, and *El* followed afterwards. *Ar*, *Ag*, and *Va* were the least selected options, but they cannot be marginalised as they still represent approximately 40% of all involved participants' views.

Table 1. IP Key Decision Considerations for AMSCs

Decision Consideration	Results
Mechanisms for Securing Intellectual Property *(Me)*	90%
Parties Involved in the Intellectual Property Life Cycle *(Pa)*	83%
Implications for Securing Intellectual Property *(Im)*	66%
Underlining Motives for Securing Intellectual Property *(Un)*	62%
Eligibility Awareness on Securable Intellectual Property *(El)*	55%
Valued Roles of Intellectual Property *(Va)*	41%
Agents of Intellectual Property Violation *(Ag)*	41%
Artefact Embodiments of Intellectual Property *(Ar)*	38%

Furthermore, due to participants' multiple responses, it was deemed relevant to explore their response pattern based on both qualitative combinations involved and quantitative options selected. The quantitative volumes reaffirmed each decision consideration's relevance because all *8 considerations* (14%) were selected in multiple instances. Selected consideration decreasingly varied stepwise, down to a minimum of *2 considerations* (3%) being the least number of options in the selection pattern, which suggested that the complexity of choices is far from a unitary circumstance. Nevertheless, several chosen option patterns emerged and ranged from *3 considerations* (17%) to *5 considerations* (21%), where *4 considerations* (34%) dominated all the choices. *7 considerations* (3%) and *6 considerations* (7%) were among the least selected options.

When the response pattern was explored qualitatively, it was observed that 22 response patterns (<10%) emerged out of the 255 possible combinations calculated ($\sum_{n=1}^{8} nC8$). The 22 response patterns comprised many unique patterns that were represented once (3%), collectively making up about 59% of respondents, thus suggesting potential heterogeneity in views. The remaining 41% of respondents' selection patterns were distributed across double (7%) and quadruple (14%) sections by participants, which dominated as the popular response pattern in the entire lot. Interestingly, the major qualitative response pattern comprised all *8 considerations* (*Me* to *Ar*), whereas the remaining double selections comprised *4 considerations* (*Im* to *Pa*; and either *El* or *Un*) and *5 considerations* (*Me* to *El*; *Un*; and either *Im* or *Ag*). Furthermore, these 'top tier' qualitative response patterns confirmed our initial findings by revealing that *Me* was the most popularly included option in all combinations; then the following in descending order of representation popularity *Pa*, *Im*, *Un*, *El*, *Va*, then *Ag*, and *Ar* were equally represented.

A contingency matrix was developed to address our test hypothesis for the potential associations between decision consideration pairs (see Table 2). It was observed that *Me* and *Pa* were top-ranked co-considerations. Yet, a handful of their combinations with other considerations (*Im*, *Un*, and *El*) were popularly represented by the total participants involved. Meanwhile, *Ar* was the least popular choice, but it demonstrated top co-considerations with *Me*, *Pa*, and *Va*.

Table 2. Contingency Matrix of Considerations

Tag ID	*Pa*	*Im*	*Un*	*El*	*Va*	*Ag*	*Ar*
Me	79%	62%	52%	55%	38%	34%	31%
Pa		55%	55%	48%	34%	31%	31%
Im			41%	41%	31%	24%	24%
Un				34%	31%	31%	24%
El					21%	24%	24%
Va						21%	28%
Ag							24%

These results suggested interconnectivity among decision considerations, so inferential statistical testing of the hypotheses ($1H_1$ or $1H_0$) was conducted using Fisher's exact method for testing association among decision considerations pairs. Test results revealed a significance with *Va* and *Ar* (two-tailed p=.018); and a near significance for *Me* and *Pa* (two-tailed p=.068), as well as *Me* and *El* (two-tailed p=.078) so, enabling us to reject the null hypotheses ($1H_0$).

Also, hypotheses ($2H_1$ or $2H_0$) tests on the potential association between participants' decision considerations and their roles were explored via another contingency matrix (see Table 3). It was found that Engineers and Managers shared a strong preference for *Me*, *Pa*, and *Im* considerations. The results further suggested that Managers and Engineers disagreed regarding *Un*; whereas Managers selected this in their top 3, it was one of the least chosen by Engineers. On the other hand, Academics indicated top consideration preference for both *Pa* and *Un* over *Me*. Meanwhile, Consultants seemed to indicate almost all considerations equally.

Table 3. Contingency Matrix of Roles vs Consideration

Tag ID	Consultant	Engineer	Manager	Academic
Me	7%	38%	34%	10%
Pa	7%	31%	31%	14%
Im	7%	28%	28%	3%
Un	3%	17%	28%	14%
El	3%	28%	17%	7%
Va	3%	17%	14%	7%
Ag	7%	14%	17%	3%
Ar	3%	17%	14%	3%

Additional testing on association using Fisher's exact method revealed that all roles had insignificant relationships with their chosen patterns, thus, enabling us to accept the null hypotheses ($2H_0$). This suggested that regardless of their organisational roles, each person had to make their own IP decisions.

4. DISCUSSION

The results from Table 1-Table 3 provide perspectives on observed response patterns of represented decision considerations and suggested interrelations. Let's begin with the bottom three ranked decision considerations (*Ar*, *Ag*, *Va*), which appear to be a subset of considerations that informs explicit action-based decisions. This trio of decision considerations appear to reflect the dichotomy between using an offensive strategy (enforcing exclusion rights to exercise market power) or a defensive strategy (navigating enforcement cautiously to establish market presence) to manage IP assets based on a clear understanding of IP issues on-hand within the AMSC (Fisher and Oberholzer-Gee 2013). Especially since *Va* and *Ar* emerged as the only pair confirmed to have a statistically significant and relatively strong association (two-tailed p=0.018), they provide a subjective appreciation for the transformative nature of manufacturing IP value shifting between cyber and physical AMSC domains. So, Fisher's (2001) IP theories provide interpretive directions to suggest that the extent of IP security and management strategies being employed or recommended could be based on AMSC actors' alignment towards IP as an asset. Thus, AMSC actors could view IP as possessing utilitarian value, fruits of their deliberate efforts, providing individualised gratification, or establishing societal benefits, which go together with their chosen IP strategy deemed suitable for its existing target domain.

Nevertheless, considering the exploratory nature of this study and statistical testing of probabilities on the sample size, it was imperative not to ignore the pairs *Ag* and *Ar*, and *Va* and *Ag,* at the expense of blindly following statistical significance, as cautioned by Figueiredo et al. (2013). Despite the other pairs being considered independent, we argue that it does not dismiss the evidence from response patterns and their association. We, therefore, infer, regarding the bottom trio set, that before securing IP and managing IP within the AMSC, one may question their actions internally by reflecting on AMSC structure queries like: *which states does the IP exist in? which ways may the IP be infringed? what is the level of appreciation for IP?* Accordingly, this may originate from literature perceptions that have split IP security and management within AMSC between technical protection measures and legal enforcement rights, probable IP state

"fluidity" across AM cyber and physical spaces, while considering potential malicious actors that may exploit AMSC vulnerabilities. Overly focusing management decisions on defensive or offensive IP strategies for interactions within AMSC has equally triggered criticisms about possibly stifling innovation or behaving anti-competitively when managing AM's emerging technologies, trade structures, and associated business models (Ballardini *et al.* 2018, Rimmer 2019).

This now brings into perspective the higher-ranked decision considerations (*Me*, *Pa*, *Im*, *Un*, *El*) to also draw contextual meanings, based on speculative inferences backed by logical explanations, that these decision considerations may be conspicuous action-based decisions. Consequently, these decision sets suggest practical triggers that align with using the previously introduced offensive or defensive IP management and security strategy within AMSCs. Beginning with the results gravitation towards *Me* and *Pa* provides interesting affirmatory insights to sections of literature that have primarily focused on proposed security techniques for successfully managing IP for AMSCs within cyberspace (overlapping functions of data, human, and system) as an integral part of AMSC operations (Edgar and Manz 2017); evidently emerging as the popular two considerations that were chosen together, as indicated by participants response, to suggest that they are complexly interrelated to tackle elements singly. Similarly, *Me* and *Pa* emerged as near-pass statistically significant associations between the two variables (two-tailed p=0.068). However, co-selection patterns suggested a strong association, such that one's actions on the methods used to manage or secure IP in AMSCs, would depend on one's relationship with or influence over the SC actors one interacts with for IP to flow freely or restrictedly within the AMSC.

This brings the next ranked set of decision considerations on *Im* and *Un* into perspective to suggest that efforts in securing and managing IP trigger considerations about the effects of such actions and may lead towards some form of balance that seeks to overcome problems of clenching firmly onto IP without it fulfilling the intended goal for securing it within AMSCs in the first place. Inevitably, SC actors may aim for gains over their IP, yet without clarity on underpinning motives for that IP; it may lead to adverse effects on the entire AMSC, which already is deemed as a germane avenue for IP infringement due to less understanding and lack of legal sophistication to hinder such unseen efforts (Osborn 2019). During the COVID-19 pandemic, there was evidence of some balancing considerations around managing and securing IP with AMSC, where actors used the "Open Covid Pledge" in sharing IP for collaborative efforts to address the medical emergencies on hand with traditional SC failures, including the use for AM to produce critical parts that were compliant with medical regulations. Contrarily, IP infringement cases and suggestive cases where IP became a barrier towards the global response were reported (Kunovjanek and Wankmüller 2020, Mahr and Dickel 2020, Troxler 2022). IP complexities emerged for AMSC actors to reconsider exemptions to their default IP withholding or sharing strategies for each situation.

Granted, considerations on *Me*, *Pa*, *Im*, and *Un* may suggest a logical combination, yet the potential knowledge gaps that exist when dealing with IP have remained a fundamental topic in literature ever since AM advanced into commercial and industrial SCs. This, therefore, provides some justification for the position of *El*, that have triggered several discussions on AM digital model data, AM physical output components, and a combination of both to support economic value adding rationale for investing in AM when considering the overall SC and IP lifecycle costs (Sepp *et al.* 2016, Feldmann and Pumpe 2017). Furthermore, response patterns reflected *El* association with *Me*, *Pa*, *Im* and *Un* but more strongly interrelated to selecting a potential strategy for securing IP; however, only *El* and *Me* were close to a statistically significant association between the two variables (two-tailed p=0.078). Once again, co-selection patterns suggested a moderate association such that one's awareness of IP rights and exemptions may inform the type of security and management technique applied, especially when deciding between public registration versus private confidentiality using formal legal methods.

Overall, it is interesting that none of these decision considerations emerged as having statistically significant associations with participants' roles. However, it may suggest additional evidence of IP risks and mitigation efforts being part of each role's responsibility within an organisation when operating within AMSCs. Yet the response patterns indicate that Managers, Engineers, and Academics are likely to focus heavily on conspicuous action-based decisions; meanwhile, Consultants tend to incorporate influencing reflexive-based decisions into their choices. We speculate this may be the case for the former due to dependency on organisational IP management and security practices. In contrast, the latter may have encountered multiple perspectives from successful and unsuccessful techniques within AMSC. Supporting IP's continued relevance within AMSCs, Xin and Xiang (2015) revealed several IP litigation cases as evidence of legal enforcement taking place to confirm that IP remains essential; thus, one must be strategically vigilant about securing and managing IP within AMSCs. This also highlights eligibility concerns with different existing legal protection methods for IP. Ultimately, these issues remain relevant because security and management of IP within AMSCs remain as important life cycle considerations for manufacturing companies (George *et al.* 2019); therefore, empirical confirmation of the discussed decision considerations reveals them as having interrelated relevance abductively from participants' responses patterns, with statistical support for inferences where applicable.

5. CONCLUSIONS

This paper expands on research concerning comprehensive IP management issues within AMSCs by providing empirically quantified insights into crucial decision considerations derived from theory and practice. Our study's results indicated that participants considered all presented options in their decision-making on IP within AMSCs. Yet, their responses were inclined more towards *Me* (90%) and *Pa* (83%) and less towards *Ag* (38%) and *Va* (41%). The analysed result from participants' response patterns confirmed that IP management and security decisions within AMSCs are multifaceted and complexly interrelated, regardless of one's organisational role. Literature was used to verify and extend our findings on

plausible explanations and actionable priorities to steer through IP complexities within AMSC via abductive reasoning. This can support efforts by practitioners in harmonising their IP management and security strategies by understanding key decision considerations and interrelations they may encounter, thus setting a foundation for future research studies to build upon. A limitation identified with the quantitative approach is the sample size being challenged with validity for generalisation; however, this is deemed sufficient for our exploratory investigation being backed by decision considerations abstracted from literature.

Future research could focus on increasing the sample size to involve more varied participant for strengthened validity on generalisation; employing alternative or non-statistical methods to gain an understanding of the relative priorities of decision considerations that is supported by situational context behind participants' choices to elucidate motives; investigating strategic decisions by SC actors to balance managing and securing IP of AM applications within the SC, to facilitate navigation the colossal ethical, legal, business, and technical management constraints of AM adoption decisions.

ACKNOWLEDGEMENT

This paper contains research, which is part of the lead author's PhD research, supervised by a team including most co-authors. The lead author's PhD research is supported by a scholarship from the University of Strathclyde. We want to thank Graeme McLaughlin, a member of the PhD supervision team.

REFERENCES

Adu-Amankwa, K., Corney, J., Rentizelas, A., and Wodehouse, A., 2022. Intellectual Property Management Challenges of Additive Manufacturing in Replacement Part Supply Chains. *IFAC-PapersOnLine*, 55 (10), 1527–1532.

Agresti, A., 2007. *An Introduction to Categorical Data Analysis*. 2nd ed. Hoboken: John Wiley & Sons, Inc.

Ballardini, R.M., Flores Ituarte, I., and Pei, E., 2018. Printing spare parts through additive manufacturing: legal and digital business challenges. *Journal of Manufacturing Technology Management*, 29 (6), 958–982.

Boland, A., Cherry, M.G., and Dickson, R., eds., 2017. *Doing a Systematic Review*. London: SAGE Publications Ltd.

Bryman, A. and Bell, E., 2019. *Social Research Methods*. 5th ed. Don Mills: Oxford University Press Canada.

Chan, H.K., Griffin, J., Lim, J.J., Zeng, F., and Chiu, A.S.F., 2018. The impact of 3D Printing Technology on the supply chain: Manufacturing and legal perspectives. *International Journal of Production Economics*, 205, 156–162.

Daly, A., 2016. *Socio-Legal Aspects of the 3D Printing Revolution*. Socio-Legal Aspects of the 3D Printing Revolution. London: Palgrave Macmillan.

Easterby-Smith, M., Thorpe, R., and Jackson, P.R., 2015. *Management and Business Research*. 5th ed. London: SAGE Publications Ltd.

Edgar, T.W. and Manz, D.O., 2017. *Research Methods for Cyber Security*. Research Methods for Cyber Security. Cambridge.

Ezell, S. and Cory, N., 2019. *The Way Forward for Intellectual Property Internationally*.

Feldmann, C. and Pumpe, A., 2017. A holistic decision framework for 3D printing investments in global supply chains. *Transportation Research Procedia*, 25, 677–694.

Figueiredo Filho, D.B., Paranhos, R., da Rocha, E.C., Batista, M., da Silva Jr., J.A., D. Santos, M.L.W., Marino, J.G., Rocha, E.C. da, Batista, M., Silva Jr., J.A. da, Santos, M.L.W.D., and Marino, J.G., 2013. When is statistical significance not significant? *Brazilian Political Science Review*, 7 (1), 31–55.

Fisher, W., 2001. Theories of intellectual property. *In*: S. Munzer, ed. *New Essays in the Legal and Political Theory of Property*. Cambridge: Cambridge University Press.

Fisher, W.W. and Oberholzer-Gee, F., 2013. Strategic Management of Intellectual Property: An Integrated Approach. *California Management Review*, 55 (4), 157–183.

Friedrich, A., Lange, A., and Elbert, R., 2022. Make-or-buy decisions for industrial additive manufacturing. *Journal of Business Logistics*, 43 (4), 623–653.

George, A., Newell, A., and Papakostas, N., 2019. Intellectual Property Protection and Security in Additive Manufacturing. *In*: *Proceedings of the 17th International Conference on Manufacturing Research*. Belfast: IOS Press, 238–243.

Gibson, I., Rosen, D., Stucker, B., and Khorasani, M., 2021. *Additive Manufacturing Technologies*. 3rd ed. Additive Manufacturing Technologies. Cham: Springer International Publishing.

Hannibal, M. and Knight, G., 2018. Additive manufacturing and the global factory: Disruptive technologies and the location of international business. *International Business Review*, 27 (6), 1116–1127.

Hugos, M., 2018. *Essentials of Supply Chain Management*. 4th ed. Hoboken: John Wiley & Sons Inc.

Kunovjanek, M. and Wankmüller, C., 2020. An analysis of the global additive manufacturing response to the COVID-19 pandemic. *Journal of Manufacturing Technology Management*, 32 (9), 75–100.

Mahr, D. and Dickel, S., 2020. Rethinking intellectual property rights and commons-based peer production in times of crisis: The case of COVID-19 and 3D printed medical devices. *Journal of Intellectual Property Law & Practice*, 15 (9), 711–717.

Noam, E.M., 2019. Intellectual Asset Management. *In*: *Managing Media and Digital Organizations*. Cham: Springer International Publishing, 235–296.

Osborn, L.S., 2019. *3D Printing and Intellectual Property*. Cambridge: Cambridge University Press.

Paczkowski, W.R., 2021. *Business Analytics*. Cham: Springer International Publishing.

Rea, L.M. and Parker, R.A., 2014. *Desiging and Conducting Survey Research: A Comprehensive Guide*. 4th ed. San Francisco: Jossey-Bass/John Wiley & Sons.

Rimmer, M., 2019. ClearCorrect: Intellectual Property, 3D Printing, and the Future of Trade. *Gonzaga Journal of International Law*, 55–96.

Sallis, J.E., Gripsrud, G., Olsson, U.H., and Silkoset, R., 2021. *Research Methods and Data Analysis for Business Decisions: A Primer Using SPSS*. Cham: Springer International Publishing.

Saunders, M.N.K., Lewis, P., and Thornhill, A., 2019. *Research Methods for Business Students*. 8th ed. Harlow: Pearson Education.

Sepp, P.-M., Vedeshin, A., and Dutt, P., 2016. Intellectual Property Protection of 3D Printing Using Secured Streaming. *In*: T. Kerikmäe and A. Rull, eds. *The Future of Law and eTechnologies*. Cham: Springer International Publishing, 81–109.

Soares, M.N. and Kauffman, M.E., 2018. Intellectual property law in the fourth industrial revolution: trade secrets risks and opportunities. *Revista Jurídica*, 4 (53), 199–224.

Troxler, P., 2022. Plan C – Makers' Response to Covid-19. *The Journal of Peer Production*.

Villafaña-Díaz, L. and Lezama-De La Rosa, M., 2020. Literature review on industry commercialization and transfer of technology 4.0. *Journal of Technological Prototypes*, 1–9.

Weber, R.H., 2001. Does Intellectual Property Become Unimportant in Cyberspace? *International Journal of Law and Information Technology*, 9 (2), 171–185.

Xin, L. and Xiang, Y., 2015. Potential Challenges of 3D Printing Technology on Patent Enforcement and Considerations for Countermeasures in China. *Journal of Intellectual Property Rights*, 20, 155–163.

Yampolskiy, M., Andel, T.R., McDonald, J.T., Glisson, W.B., and Yasinsac, A., 2014. Intellectual Property Protection in Additive Layer Manufacturing: Requirements for Secure Outsourcing. *In*: *Proceedings of the 4th Program Protection and Reverse Engineering Workshop - PPREW-4*. New York, New York, USA: ACM Press, 1–9.