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Examining Replacement Part Supply Chain links with Intellectual Property Issues when using Additive Manufacturing

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Abstract: Additive manufacturing has made headlines in the research and practice community, especially for making or servicing replacement parts in what is sometimes called "digital spare parts". Although this practice may not be considered new, the supply chain disruption introduced during global pandemics and conflicts helped confirm the viability of using additive manufacturing for replacement part applications; however, among the issues that are associated with this practice concerns about intellectual property can often become an unforeseen barrier to surmount when dealing with managing the value of intangible assets in supply chains; which have been highlighted by some scholars in literature. Despite this, the extent of additive manufacturing processes' exposures to intellectual property compromise in replacement part applications and the likelihood of stakeholders addressing these vulnerabilities in the supply chain context remain empirically underexplored. Thus, this paper seeks to fill that void by surveying the views of experts in the field and analysing their response patterns concerning perspectives established in the literature. The empirical findings are expected to inform key stakeholders on prevalent concern orientations towards these issues and make the necessary adjustments when considering intellectual property management for additive manufacturing use in replacement parts applications within the context of supply chains.

Keywords: Replacement Part, Intellectual Property, Supply Chain Management, Additive Manufacturing, Likert Scale

1. INTRODUCTION

The technological and industrial revolution for the manufacturing sector includes Additive Manufacturing (AM) as a hot topic for research and practical applications in our modern era. AM is mainly favoured for its characteristics in fabricating 3D physical objects from 3D digital model data by "joining and curing" material in successive layers (Wohlers Associates 2023). AM applications have evolved over the years from functioning prototyping to end-use components; among popularly favoured applications include replacement parts (also called "digital" spare parts), especially in supply chain complexities. Mainly due to the nature of a Replacement Part (RePt) being a stocked component primarily intended to "replace" or "repair" a corresponding failed component to restore the original required function of a product (Slater 2017). Among the legal and management issues that are prevalent in literature, Intellectual Property (IP) is often a contentious one primarily due to its intangible nature and being creations of the human mind that can be leveraged as captured, shareable and replicable value and are protected under applicable laws (Poltorak and Lerner 2011). So traditionally, a RePt on its own could face limitations on the type of IP regimen that is considered appropriate because it is likely internalised as forming a part of another component or equipment and, therefore, dependent on the collective protective claims under the law (Takenaka 2019). It, thus, comes as no surprise that contention among protective intents, anti-monopoly legislation, and sustainability ethos surrounding RePts and IP within SC contexts has triggered the attention of scholars and practitioners when the complexity is shifted in parallel to the digital and physical via AM; moreover, some experts predict that the future of RePts could be centred around trading IP of these RePts and less of the physical parts to all AM production (Geissbauer *et al.* 2017).

IP security issues associated with RePts made by AM in SCs are under investigation by scholars and practitioners, with a few identified studies' perspectives highlighted here. Flank *et al.* (2017) raised concerns about the need to identify authentic parts made by AM, especially with RePt due to the prevalent issues of counterfeit RePts embattling industries like

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aerospace and defence, resulting in waned assurances and calls for needed certification guarantees on IP authenticity. Meanwhile, Durão *et al.* (2017) explored distributed RePt production by AM through two multinational SC scenarios where IP issues were a focal analysis to reveal that IP control becomes challenging with the independent evolutions of SC configurations shifts from centralised to distributed systems that harness the potential of AM; thus make IP protection challenging. Ballardini *et al.* (2018) investigated the digital sourcing nature of AM use for producing RePts concerning technology, business, and IP issues in AM RePt markets to emphasise the tensional uncertainties between "repair" vs "make" of IP doctrines when using AM to make or service RePt, on top of calls for review of IP protection on digital model data (CAD) due to their crucial role. Similarly, Kim *et al.* (2019) highlighted the potential of AM use for RePts on-site to perform maintenance functions by retrieving digital models from part library-based information systems, yet they acknowledged that IP protection remains a limitation to this potential. Meanwhile, Boer *et al.* (2020) investigated the impact of AM applications for RePts within SCs of armed forces during military and humanitarian missions on several roles, including IP, where they revealed that IP and its royalties must be addressed taking into account regional and national regulations on availing access to digital RePt designs under RePt service contracts for expeditionary military operations. Whereas Salmi *et al.* (2020) highlighted the unlocked SC potential for AM of RePts during the COVID-19 pandemic and identified the emergent issues of these "unregulated" RePt SCs on IP security when multiple SC players get involved to offset production shortfalls of OEM curtailed capabilities. In contrast, Zhang *et al.* (2022) highlighted the potential of IP licensing of digital RePts in SCs from OEM perspectives to indicate that IP licensing could play a crucial enabling role for parties involved in such SC configurations. Furthermore, Adu-Amankwa *et al.* (2022) explored concern levels on IP issues about AM use for RePts within SCs via multiple interrelated IP, AM, SC and RePt security categories to suggest guidance on control and management circumstances that are perceived to require priority attention.

As mentioned earlier, the studies demonstrate efforts towards understanding the prevalent IP issues that could emerge when AM is used to make or service RePts within SC. It undoubtedly reveals growing attention given to IP issues but remains underrepresented compared to the myriad of literature focusing on operations when considering AM and RePtSCs. Furthermore, most studies do not measure these issues' empirical applicability and likelihood specifically from IP methods, AM exposures, and SC players collectively. We argue that RePts made or serviced by AM within the SC context need some clarity on the perceived extent to which these issues likely occur and their extent of being applicable to the unique case of RePts. This is especially deemed relevant in our current era of digitalisation, which has birthed "direct digital manufacturing" of RePts via the popular digital spare parts models. Indeed, such an investigation eventually results in empirically measuring and understanding several IP, AM, and SC related security issues connected to RePts, which are often theoretically or conceptually described.

Hence, this paper aims to explore the views of stakeholders (practitioners and academics) on the extent of likelihood relevance of prevalent intellectual property issues to supply chains using additive manufacturing to make components and the intellectual property issues applicability to additive manufacturing being used to make or service replacement parts in a supply chain context. This paper is organised as follows: *Section 2* outlines methodology; *Section 3* presents findings; *Section 4* discusses outcomes and concludes.

2. APPROACH AND METHOD

A literature review was conducted to identify three main groups of enquiries relating to IP issues on AM applications within RePtSC, which entailed: **(1)** *IP methods that are preferred to deploy within RePtSC for AM applications*; **(2)** *AM exposures that may be exploited or exposed within RePtSC for IP compromise (AM exposure)*; and **(3)** *SC players within AM ecosystems that were deemed as potential risks for IP compromise*. However, this paper shall focus on security vulnerabilities via conscious or unconscious AM exposures for IP compromise regarding RePts applications within SC contexts. Discoveries from the literature were operationalised into identifiable categories that were eventually grouped as 11 AM exposures. The 11 AM exposures entailed:

- *Data Sourcing* comprises acquiring the 3D model data via external sourcing, 3D scanning, reverse engineering existing data or internal retrieval of stored point cloud data.
- Design Specifications (*Design Specs*) comprise the activities of firming up the geometric and functional properties via CAD model generation to represent designs.
- Manufacturing Process Specifications (*Mfg Process Specs*) comprise locking in manufacturing methods and build parameters suitable for actualising the finalised designs.
- Material Property Specifications (*Material Specs*) comprise locking in suitable material from the design and for the manufacturing methods to actualise the final designs.
- Manufacturing Equipment Operations (*Equipment Ops*) comprise direct or remote activities and parameter orientation with equipment to build the designed component.
- Pre-Processing Specifications (*Pre-Processing*) comprise preparing equipment and design files for conversion into instructional code used to build the designed component.
- Post-Processing Specifications (*Post-Processing*) comprise activities to retrieve the output component from the build platform and apply necessary finishing properties.
- Verification Requirements (*Verification*) comprise quality checks to ensure that the manufactured component was built and will perform in accordance with design intents.
- *Manufactured Part* comprises the final output component that emerges as a physical equivalent of the digitally designed 3D model and the entire manufacturing steps.

- Required Support Services (*Support Services*) comprise auxiliary and complementary digital or physical services that support phases for designing or building components.

- File or Format Conversion (*File/Format Convn*) comprises the transition of component model data into digital or physical states for direct design or building tasks.

The categories and enquiries formed the foundation of an online questionnaire as the main instrument used to survey participants' perceptions within the wider AM community. Consequentially, an online survey was piloted, rectified, and deployed via Qualtrics as a self-administered questionnaire. A purposive sampling strategy was used to identify and recruit 37 respondents from diverse roles *(46% Managers, 30% Engineers, 11% Professors, 8% Advisors, and 5% Lawyers)* and organisations *(43% Commercial, 40% Research, 14% Academic, 3% Government)*, who eventually took part in this study out of 40 invited candidates. The respondents were expected to have knowledge or experience about AM, IP, SC or RePts and associated issues.

During the data collection stages, participants identified the relevance of a list of 11 AM exposures aggregated from the literature. Follow-up questions were then asked to "ladder down" on their applicability and likelihood to learn more about their choices (Easterby-Smith *et al.* 2015). Responses to Likert-type questions on the applicability of AM exposures to RePts and the likelihood of acting on them form the basis of this paper. The responses were treated as ordinal variables, which were analysed using descriptive statistics with the aid of SPSS to explore patterns of applicability and likelihood. Also, due to the ordinal distribution of each AM exposure based on sentiments, a pseudo-consistency was examined by cross-mapping sentiment categories for analysis (Easterby-Smith *et al.* 2015). This sought to explore empirical evidence on the extent of generic IP issues about AM applications within RePtSC contexts; thus, literature was consulted to derive abductive meanings from the emergent results.

3. RESULTS AND FINDINGS

The responses from participants are captured into two groups: Applicability (consisting of the response options of Applicable=*Apble*, Neutral=*Neul*, Inapplicable=*Inble*) and Likelihood (consisting of the response options of Likely=*Liky*, Neutral=*Neul*, Unlikely=*Unly*). The labels are abbreviated to fit within Table 1 and Table 2 spaces whilst capturing Responded=*Respd* as the summed results per AM exposure.

Table 1 presents views about the specific applicability of listed 11 AM exposures for RePts, while Table 2 presents views about their generic likelihood to act upon them. Out of the 11 AM exposures presented to participants, summed results per category revealed top-ranked encounters with Design Specs (57%), followed by Mfg Process Specs (49%), Data Sourcing (48%), Manufactured Part (46%) and Pre-Processing (46%), with the least being Verification (22%) and Support Services (22%), while being preceded by File/Format Convn (32%). Meanwhile, Equipment Ops (41%) emerged slightly ahead of both Material Specs (40%) and Post-Processing (40%).

Table 1. Applicability of AM Exposure for RePt

AM Exposure	Respd	Inble	Neul	Apble
Design Specs	57%	0%	16%	38%
Mfg Process Specs	49%	5%	8%	32%
Data Sourcing	48%	0%	11%	35%
Manufactured Part	46%	3%	14%	30%
Pre-Processing	46%	0%	8%	35%
Equipment Ops	41%	3%	8%	27%
Material Specs	40%	0%	14%	24%
Post-Processing	40%	5%	5%	30%
File/Format Convn	32%	3%	0%	30%
Verification	22%	0%	5%	16%
Support Services	22%	0%	3%	19%

Table 2. Likeliness of acting on AM Exposure to IP in SC

AM Exposure	Respd	Unly	Neul	Liky
Design Specs	57%	0%	8%	49%
Mfg Process Specs	49%	3%	11%	35%
Data Sourcing	48%	5%	5%	38%
Manufactured Part	46%	8%	8%	30%
Pre-Processing	46%	0%	8%	38%
Equipment Ops	41%	3%	8%	30%
Material Specs	40%	0%	8%	32%
Post-Processing	40%	8%	8%	24%
File/Format Convn	32%	3%	5%	24%
Verification	22%	3%	3%	16%
Support Services	22%	0%	3%	19%

For AM exposures, Table 1 and Table 2 reveal that respondents indicated mostly positive applicability to RePts by each AM exposure *(16%-38%)*, while they similarly indicated mostly positive likelihood to act upon each AM exposure *(19-49%)*. Design Specs, Data Sourcing, Pre-Processing, and Mfg Process Specs dominated strong positive sentiment patterns on applicability and likelihood. Though the views on Verification and Support Services were minimally represented, they indicated consistent positive inclinations on applicability and likelihood. More neutral opinions existed about applicability (≤16%) compared to that of likelihood (≤11%), thus suggesting increased uncertainty on RePts for each AM exposure, especially for Design Specs, Material Specs and Manufactured Part, which increased from 8% to 14%, 14% and 16% respectively. In contrast, Mfg Process Specs decreased from 11% to 8%. Meanwhile, few views on negative applicability and likelihood were expressed (8%, 5% and 3%). Interestingly, only File/Format Convn has a 0% neutral view on AM exposure being applicable to RePts.

When the applicability central tendencies of responses to each AM exposure were calculated, the emergent pattern revealed that the median sentiment for Data Sourcing, Design Specs, Mfg Process Specs, Material Specs, Equipment Ops, Pre-Processing, Post-Processing, Verification, Manufactured Part, Support Services, and File/Format Conv each interestingly fell into the positive applicability response, despite the existence of neutral and negative applicability responses, which reaffirmed that participants mainly were positively inclined towards all AM exposures with no uncertainty about its applicability and negative likelihood. Similarly, when the likelihood central tendencies of responses to each AM exposure was calculated, the emergent pattern revealed that the median sentiment for Data Sourcing, Design Specs, Mfg Process Specs, Material Specs, Equipment Ops, Pre-Processing, Post-Processing, Verification, Manufactured Part, Support Services, and File/Format Convn each interestingly fell into the positive likelihood response, despite the existence of neutral and negative likelihood responses, which reaffirmed that participants mainly were positively inclined towards all AM exposures likelihoods with no uncertainty about its likelihood and negative applicability.

Additional data exploration conducted by cross-mapping AM exposure responses' co-occurrence representations on the ordinal scales for applicability (Inble, Neul, Apble) versus likelihood (Unly, Neul, Liky) revealed that participants mostly had consistent co-occurring Apble-Liky sentiments. Yet, the ranking changed in some instances because not every participant indicated the same sentiment for each applicability and likelihood category. Nevertheless, it was interesting to discover that Design Specs (32%) emerged as the most prominent co-occurring sentiment; this was then followed by the co-occurrence sentiments for Pre-Processing (30%), which leapt forward into second place by overtaking Mfg Process Specs (27%) and Data Sourcing (27%) which had co-equal co-occurrence sentiments. Manufactured Part (24%) emerged as the next-placed co-occurrence sentiment, which was closely followed by both File/Format Convn (22%) and Equipment Ops (22%). Interestingly, Post-Processing (16%) slightly led to the least co-occurring sentiments that were surprisingly represented jointly by Material Specs (14%), Verification (14%) and Support Services (14%). Overall, the co-occurrence range shrunk to 14%-32% on positive sentiments towards AM exposure applicability and likelihood (Apble-Liky). Meanwhile, the co-occurring sentiments towards uncertainty and negative sentiments dropped to cover a range of 0%-5% (Neul) and 0%-3% (Inble-Unly) representations.

4. DISCUSSION

The descriptive results in Table 1 and Table 2 generally revealed that participants deemed each AM exposure relevant to the issues being studied. This is evident in all options selected not less than twice (*see Respd columns*), despite varied opinions on applicability to RePt and likelihood to occur cases. Furthermore, the emergent response patterns on central tendencies via each median value reveal mostly positive inclinations across the board on applicability and likelihood, which provides additional insights on the relevance of these issues and generic indications on the perceived level of relevance by the respondents; therefore, corroborating the theoretical justifications of deriving these categories from literature (Snijkers *et al.* 2013). The discussion shall delve into the AM exposure nuances that emerged as prominent, coupled with perspectives on IP compromise and SC risks.

Let's begin with the AM exposures to IP compromise that may be exploited within RePtSC, considering its applicability to RePts and the likelihood of acting on its AM exposures. The emergence of Design Specs (57%) over Mfg Process Specs (49%) as a prominent AM exposure indicates that the respondents generally had greater wearies on the IP vulnerability of Design Specs or Mfg Process Specs falling into the undesired hands. AM security literature confirm that illicit access to such information is surprisingly achievable; thus, scholars like George *et al.* (2019) associate IP risks emerging from product specifications being used or misused beyond claims and even being infiltrated with malicious or unauthorised alterations; these actions can affect the entire RePts production and market value, especially in the light of beliefs that AM allows one to side-step the R&D commitments made by a competitor. Thus, access to these Design Specs and Mfg Process Specs may affirm this plausibility despite the counter debate on the variety of AM processes require some form of practical or technical know-how to determine whether a design is suitable for a chosen process rather than perceiving a one-design-fit on all AM processes (Hoskins 2018).

Perhaps these AM exposures may seem like a fairy tale; however, if one considers the involuntary means of IP leaks within SC actors offering manufacturing-as-a-service or collaborating in manufacturing process development projects for clients, there are legitimate concerns about the extensive and diversified capabilities of such "3D-Print Houses". This is often due to 3D-Print Houses' engagement with various AM production jobs and their crucial role in actualising the design model data (CAD or Build files) into physical output part, in addition to the retained know-how in discovering AM settings that work best for application cases so that they could be risks of IP leaks from one client's project into another client's parts (Rehnberg and Ponte 2018). Notwithstanding, it is not farfetched for IP owners of RePts to employ AM security measures that can provide control over Design Specs and Mfg Process Specs across cyber, physical or cyber-physical systems rather than dealing with the legalities of raising a formal case and evidencing IP infringement took place, especially in light of the growing rate of cyber-attacks, information theft, ransomware, or malware threats within global supply chains, distributed manufacturing, and concurrent engineering practices (Stjepandić *et al.* 2015).

In contrast, there are debates on the level of valuable know-how embedded into designs that can be directly extracted into an AM process amidst the much-identified needs for preparation or adaptations to AM. Undoubtedly, this remains a major challenge and concern for organisations in identifying RePts that are suitable for AM given the varied criticality levels of RePts and their resources needed to actualise an AM-version of a traditionally manufactured RePt as this goes beyond geometric reproduction and may extend into preservation of functionality (Meisel *et al.* 2016). Nevertheless, there are tensions between being able to protect one's IP using technology means in exercising exclusion and the undesirable effect of overreaching that makes IP so tightly locked down that it pays no heed to legitimate IP exemptions. Moreover, one could enjoy legally acknowledged protection on anti-circumvention to these technology means, which could account for concurrent dependency on the law to secure the IP of RePts (Adu-Amankwa and Daly 2023). A counterargument for employing such IP control emerges with Data Sourcing that requires due diligence on Design Specs and Mfg Process Specs because, in such cases, there is an additional risk that a SC player could receive and produce RePts using AM by a client who may not have the legitimate authorisation of the component IP holder. Thus, it draws in the perspectives on the role of designers being considered as another significant risk to IP compromise; since they are often regarded as custodians of the product specifications then, they may be suitable targets for hacks to extract the critical details or on the other hand due to their design knowledge play a pragmatic role in scanning existing RePts, reverse engineering product specifications and adapting them for AM (Mendis *et al.* 2019).

Reconsidering the applicability to RePts, it is well established in the literature and aforementioned in this paper that a major challenge to RePts' IP legal protections is the types of IP regimen acknowledged for these components, especially since they are usually embodied into a more extensive product or system; for example, Hartwig (2016) highlighted the challenges in making a valid case for RePts under patent, design and trademark laws, alongside the ongoing complexities with attempted claims on AM data files as worthy of copyright protection or suitable for legal protection as an instructive software (Mendis *et al.* 2019). Moreover, a SC perspective among actors involved in making or servicing RePts suggests that those positioned within the design and manufacturing phase are considered sources of AM enablement to make RePts. However, they have interestingly been mostly underestimated in literature at the initial stages of AM development, where End Users were considered the primary source of IP compromise; for example, Depoorter and Raus (2019) likened expected AM IP infringement via digital means to the lessons learned from the ongoing battles with IP control losses that occur within the media industry once digital contents are availed online to end users; nevertheless, AM uniquely opens up new SC opportunities that incorporate these SC actors to function both within AM and traditional RePt networks, therefore invariably extending the IP risks and disrupting established safeguards (Gibson *et al.* 2021).

Despite these concerns, there is evidence that AM is favoured as a technology enabler for legacy and obsolete RePt reproduction. Yet, it does not exempt it from the complexities of balancing the risk of IP compromise and legitimising repairs or replacement under the "right to repair" or "anti-monopoly" plausible with RePts; for example, Parikh (2016) highlight the complexities in direct specifications (design, process, etc.) acquisition through alternative channels apart from RePt original product manufacturers and making a legitimate case of repair as exempted under patent or design protection laws. Not all original manufacturers would agree to this claim or would be happy with their specifications being reverse-engineered or acquired without their explicit involvement, as this leads to broader AM RePts debates on market competition, consumer protection, and liability claims (Weinberg 2016).

Ultimately, AM exposures with IP compromise are applicable to RePts, and the likelihood of acting on them lies within the authority of the IP custodian, who may decide on a suitable means of enforcement. Malicious SC actors can exploit influencing factors on AM exposures to compromise the IP of RePts from within or outside an organisation, especially since attention is usually on securing IP at product or system levels for high-value items. Also, determining a RePt's suitability for AM is both a subjective and complex decision; thus, attention is usually given to RePts when they are considered to fall into the capital goods category, considered suitable for AM, and most probably when produced as a "quick-fix" for in-facility or remote-conditional repairs. Despite the diversified opinions from this study's results, the IP legal and non-legal contention remains an ongoing debate that needs a further understanding of contextual decision considerations within varied SC contexts (Adu-Amankwa *et al.* 2023).

5. CONCLUSIONS

This paper builds upon research about IP issues with AM use in RePtSCs by contributing empirically quantified insights on the extent to which these issues are deemed relevant (applicability and likelihood). Undoubtedly, debates on the IP implications of using AM for RePts and the strategic SC effects are ongoing, especially after the revelation within the pandemic that IP, though intangible, can be a significant barrier to surmount even when IP owners are known. One can only imagine the degree of uncertainty that exists regarding the allowable IP exemption to make a RePt. Literature provided some direction on the emergent findings. Yet, it was astonishing to discover that despite RePts usually being embodied within a larger assembly, every AM exposure was considered applicable and had a general positive likelihood to act upon them. Also, the added service value of availing RePts for repairs and maintenance functions may justify acting or ignoring the issue, thus alluding to the IP owner or consumer's role in sustaining the uptake of AM to make or service RePts. Realising that AM requires significant efforts for Verification to establish quality standards, and reliance on Support Services makes it understandable as the least considered AM exposures, but respondents had strong positive sentiments towards each.

As society's needs nudge towards sustainable manufacturing and consumption practices, confidence in AM use for RePts requires clarity on navigating the intangible IP barriers and enablers within SCs. It is anticipated that this study's findings may inform critical stakeholders on the prevalent concern orientations towards these issues and make the necessary adjustments when considering IP management for AM use in RePt applications within SCs. A major limitation identified with the quantitative approach is with the sample size being challenged with generalisation validity; but since statistical significance is not an objective here but rather the response distribution on sentiments (Likert), which are not necessarily facts, yet using literature to back the formulation of categories and interpret patterns help address this identified limitation.

Future research could focus on using statistical or alternative methods to gain an understanding of the pattern or factor relationship behind participants' choices for clarification, strengthen validity on generalisation by increasing the sample size to involve more varied participants, investigating application cases or scenarios to provide contextual appreciation on the complexities that exist and suggest directions to navigate AM for RePt as a sustainability enabler.

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