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Autonomous delivery robots: a legal framework for infliction of game-theoretic small penalties on pedestrians

Subhajit Basu[a], Adekemi Omotubora[b] and Charles Fox[c]

[a]School of Law, University of Leeds, Leeds, UK; [b]Faculty of Law, University of Lagos, Lagos, Nigeria; [c]School of Computer Science, University of Lincoln, Lincoln, UK

ABSTRACT
Autonomous delivery robots (ADRs) must share and negotiate for public and private space with pedestrians. Game theory shows that this requires making credible threats of inflicting at least small harms onto members of the public, which requires new legal justification. To this end, we argue that ADRs could be considered as pedestrians under existing law. We propose 'robot self-defence' and right to property as the legal basis for inflicting the required 'small penalties.' We examine the liability framework when an ADR actually causes a collision either deliberately through actualising a credible collision threat or accidentally via errors in controlling intended non-contact threats. We explore challenges around privacy and data protection where the ADR collects and uses data to model and predict interactions. Together, this provides a framework for legal operation of ADRs, including the ability to inflict small harm onto members of the public when necessary in negotiations for space.

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1. Introduction

Development and experimental deployment of autonomous vehicles (AVs), including on-road 'self-driving cars' and smaller autonomous delivery robots (ADRs) operating in pedestrian areas, has gained significant traction.[1] Primary AV functions involve navigation around inanimate and unresponsive environments, including roads, buildings, lanes, pavements, kerbs, trees, and traffic signals. Sub-tasks of navigation are localisation (determining the

CONTACT Charles Fox ChFox@lincoln.ac.uk School of Computer Science, University of Lincoln, Brayford Pool, Lincoln, LN6 7TS, UK

[1]Claudine Badue, et al. 'Self-Driving Cars: A Survey' (2021) 165 *Expert Systems with Applications* 113816.

robot's position with reference to a map), mapping (creating a map of the environment), route planning (deciding on the best course over large distances), and control (managing steering to follow the route).[2]

However, interaction between AVs and humans remains difficult, and the 'big problem' for real-world autonomous vehicles is people,[3] who must share and negotiate for space. Unlike static environments, people are complex interactive agents with their own goals, utilities, and decision-making systems, so interactions with them must take these into account to predict their actions and plan accordingly.[4] Interaction is recursive and complex: an AV's actions affect the person's actions and vice versa. This aspect is particularly crucial in areas where traffic rules do not clearly define right-of-way, such as at unmarked intersections, pavements, and other paved areas where AVs and pedestrians must negotiate passage. Understanding human road user behaviour has an entire subfield of Psychology dedicated to it – Human Factors of Transport[5] – and remains far from being fully understood or automatable. As such, operation of vehicles implementing theories of interactions may currently be considered *experiments* on non-consenting members of the public rather than trials of mature engineering technology.

The key issue in this context is the 'freezing robot problem.'[6] This occurs when an AV is programmed to prioritise safety by stopping for any road user in their path. This behaviour can then be manipulated by humans who realise they can assert dominance and push in front of it in every encounter, as observed during trials of AV buses in cities such as Trikala, Greece, and La Rochelle, France.[7] These trials show that if the public becomes aware of the AVs' deferential programming, it can lead to a standstill in AV progress, with vehicles being perpetually impeded by pedestrians and other drivers asserting the right of way.

Game theory solves the freezing robot problem[8] by demonstrating that the optimal strategy for both parties is one that is both probabilistic and

[2]Shinpei Kato, Eijiro Takeuchi, Yoshio Ishiguro, Yoshiki Ninomiya, Kazuya Takeda, and Tsuyoshi Hamada, 'An Open Approach to Autonomous Vehicles' (2015) 35 *IEEE Micro* 60–68.

[3]Rodney Brooks, 'The Big Problem with Self-Driving Cars is People' (2017) *IEEE Spectrum: Technology, Engineering, and Science News* 27 August.

[4]Fanta Camara and Charles Fox, 'Space Invaders: Pedestrian Proxemic Utility Functions and Trust Zones for Autonomous Vehicle Interactions' (2021) 13 *Int J of Soc Robotics* 1929–49.

[5]Mitchell Cunningham and Michael A. Regan, 'Autonomous Vehicles: Human Factors Issues and Future Research' (2015) 14 *Proceedings of the 2015 Australasian Road Safety Conference*; Sunil Kr Sharma, Sunil Kr Singh, and Subhash C. Panja, 'Human Factors of Vehicle Automation' (2021) *Autonomous Driving and Advanced Driver-Assistance Systems (ADAS)* 335–58.

[6]Peter Trautman and Andreas Krause, 'Unfreezing the Robot: Navigation in Dense, Interacting Crowds' (2010) *IEEE/RSJ International Conference on Intelligent Robots and Systems* 797–803; Fanta Camara and Charles Fox, 'Unfreezing Autonomous Vehicles with Game Theory, Proxemics, and Trust' (2022) *Frontiers of Computer Science*. doi.org/10.3389/fcomp.2022.969194.

[7]Ruth Madigan et al., 'Understanding Interactions between Automated Road Transport Systems and Other Road Users: A Video Analysis' (2019) 66 *Transportation Research Part F: Traffic Psychology and Behaviour* 196–213.

[8]Charles Fox, Fanta Camara, Gustav Markkula, Richard Romano, Ruth Madigan, and Natasha Merat, 'When Should the Chicken Cross the Road?: Game Theory for Autonomous Vehicle-Human Interactions'

recursive. As two agents approach each other, they should incrementally increase the probability of yielding, but maintaining a strictly non-zero probability of colliding at all times. This small probability acts as a credible threat deterrent, rarely actualised (for instance, in one out of a million interactions). Yet, its possibility is sufficient to influence the other party's behaviour. This dynamic mirrors the actions of human drivers in similar situations: they often adopt aggressive driving behaviours to imply the risk of a collision, pressuring the other (typically misbehaving) road user to yield. Occasionally, human drivers collide with the other party, typically due to an error when intending only to intimidate with a 'close call.'[9]

Causing an actual collision or creating a situation with a significantly increased risk of collision would be illegal. Dangerous driving is an offence, and intentionally causing a 'close call' could easily fall under the definition of dangerous driving if it creates a situation where harm is likely. Despite this, human drivers engage in subtle 'games of chicken' every time they cross the road or negotiate merging into traffic or changing lanes on motorways. It is rarely enforced (e.g. during the writing of this article, we obtained dashcam footage of a driver 'cutting up' one author and reported it to UK police, who informed us they would not act upon it) except in cases where a collision actually occurs. Nonetheless, deliberately programming an AV or ADR with the intent to cause death or serious injury could expose software engineers to charges of murder or manslaughter, depending on the circumstances.[10]

It can be argued that AVs do not require any changes to the law because they are engineered systems, and the law already covers engineered systems in some detail.[11] Specifically, any engineered system is designed and sold to operate within some tolerance, such as a one-in-a-million failure rate. If accidents occur below this rate, they are accepted as part of the system's specifications because accidents are a known risk. However, we argue that human factors and game theory introduce a previously unseen aspect of engineering law. Engineering systems are typically designed to maximise safety and

(2018) *VEHITS 2018: 4th International Conference on Vehicle Technology and Intelligent Transport Systems*.

[9]Gustav Markkula et al. 'A Review of Near-Collision Driver Behavior Models' (2012) 54 *Human Factors* 1117–1143.

[10]Murder in English law is defined as the unlawful killing of a human being with 'malice aforethought.' 'Malice aforethought' is traditionally interpreted as having the intent to kill or cause grievous bodily harm (GBH). Manslaughter in the UK can be either voluntary (a killing in the 'heat of the moment' or with diminished responsibility) or involuntary (a killing resulting from a reckless or criminal act). Intentionally coding an AV to collide, knowing it might cause harm, could be deemed as a reckless act leading to involuntary manslaughter. If the engineer was working under the directive or with their employer's knowledge, the company might face charges under the Corporate Manslaughter and Corporate Homicide Act 2007.

[11]Richard Jinks, 'Oxbotica Response to Law Commission Consultation on Autonomous Vehicles' (2019), <https://s3-eu-west-2.amazonaws.com/cloud-platform-e218f50a4812967ba1215eaecede923f/uploads/sites/30/2019/06/AV117-Oxbotica.pdf>

adhere to the principle of 'do no harm.' Accidents are unintended deviations from this objective. However, according to the game theory model, it is sometimes necessary to deliberately and pre-meditatively cause inconvenience or discomfort to members of the public to make any driving progress. This represents a significant departure from the design objectives of all other forms of engineering, and to our knowledge, there are no other engineered systems explicitly designed to cause discomfort, unhappiness, or inconvenience to the public.

The closest known counter-example was a psychology experiment conducted by Facebook,[12] which deliberately induced negative moods in users by displaying news stories with negative sentiments. While this experiment was criticised as morally reprehensible or unacceptable, the legal debate centred on whether Facebook obtained explicit informed consent from its users to conduct such research. Although users had agreed to Facebook's broad terms of service, many argued that this did not equate to informed consent for psychological experimentation. In contrast, with AVs, as mentioned previously, there is a clear distinction. These vehicles would be rendered immobile due to the 'freezing problem' if they were unable to deter interference with their operations, as constantly yielding to other road users would become a predictable and exploitable behaviour.

Beyond small negative utilities inflicted on pedestrians, the broader human utility must be considered, including the impact on senders and recipients of goods transported by AVs. For instance, an AV tasked with transporting urgent medical supplies might encounter delays that could critically affect a human patient reliant on these deliveries. An obstructive pedestrian could harm this patient by more than the cost of a personal space invasion.

This article focuses on commercial Autonomous Delivery Robot (ADR) type AVs rather than large self-driving cars. ADRs are characterised by operating primarily on pedestrian areas rather than roads – including sidewalks, pedestrianised streets, footpaths, and campuses. ADRs vary in size, typically ranging from scooters to mobility scooters. They are utilised for carrying deliveries, such as mail, hot food from restaurants, supermarket purchases, or medical supplies from a local depot or store to customers over the 'last mile' in urban settings. Additionally, ADRs may operate on private properties, including airport interiors and exteriors, shopping malls, factory floors, and company campuses. Although the size of these vehicles generally does not pose a fatal threat to pedestrians, collisions can still result in serious injuries, such as broken bones.

[12]Inder M. Verma, 'Editorial Expression of Concern: Experimental Evidence of Massive-Scale Emotional Contagion Through Social Networks' (2014) 111 *Proceedings of the National Academy of Sciences of the United States of America* 10779–779.

Given their shared use of pavements, we argue that ADRs could potentially be classified as pedestrians under existing UK legal frameworks. This classification would grant ADRs certain rights and responsibilities in relation to other pedestrians, including wheelchair and mobility scooter users. To maintain a credible threat of inflicting small penalties on pedestrians, we propose the concepts of 'robot self-defence' and the 'right to property' as potential legal bases. These principles could justify the imposition of small penalties on pedestrians, helping to ensure the effective operation of ADRs on shared pavements. We examine the liability framework that would apply if an ADR caused an accident.

The article is structured as follows: it first considers what recent game-theoretic models reveal about the strategic navigation of ADRs in scenarios akin to the 'game of chicken,' particularly at unmarked intersections without clear priority rules. It then reviews the legal status of ADRs in the United Kingdom, particularly in relation to their use on pavements traditionally designated for pedestrians. This is followed by a critical analysis of the ethical and legal implications of ADRs potentially inflicting 'small penalties' to ensure other agents yield the right of way or deter other wrongful interference. The discussion then turns to the concept of robot self-defence and the defence of property, justifying the ADRs' prerogative to protect themselves and their cargo. Subsequently, the focus shifts to the liability framework applicable to actual collisions in accidents due to an error when intending only to intimidate with a 'close call.' Finally, there is an examination of the data protection, bias, and discrimination concerns arising from ADRs' use of personal data and class stereotyping in controlling the interactions.

2. Engineering background

For concreteness, we will assume that an ADR is about 1 m long and 0.5 m wide, and the height without load is about 0.2 m, with a box load of about 0.8m.[13] It is designed for driving between 4mph and 8mph. The ADR does not have space dedicated to an onboard operator but typically has remote monitoring and the ability to be switched to remote manual operation from automation. The operation areas of the robot are pavements,

[13]Currently, many different concepts exist for automated delivery robots. Vehicles range from smaller pavement delivery robots (wheeled and legged models) to traditional light-duty vehicles (vans) to road-based vehicles with novel designs. While some analysts have attempted to segment robot delivery concepts using various characteristics, including vehicle type, weight, carrying capacity, speed, purpose/application/end-user, or other characteristics, such as the number of wheels or sensor suite, no definitive categorisation exists. Francisco Rubio, Francisco Valero, and Carlos Llopis-Albert, 'A Review of Mobile Robots: Concepts, Methods, Theoretical Framework, and Applications' (2019) 16 *International Journal of Advanced Robotic Systems* 1–22.

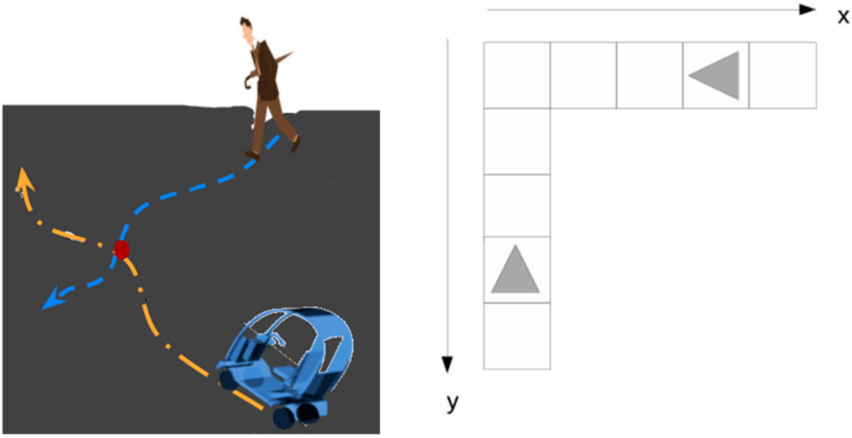

Figure 1. Left: Interaction scenario used as the basis for the game theory model. The ADR has a plan for its own future route and a prediction of the pedestrian's route, predicting where a collision will occur if neither yields. Right: Simplified game theory model of the two agents at discrete locations, speeds, and turns.

which it will share with pedestrians, motorised wheelchairs, mobility scooters, and other users.

A game theoretic model[14] demonstrates that for an autonomous vehicle (AV) to make progress in conflict situations, it must maintain a credible threat of deliberately causing a collision or inflicting some other form of penalty on the opposing agent. Figure 1 (left) illustrates the scenario assumed by the model, in which two agents meet at an unmarked intersection without clear legal precedence, forcing them to negotiate who will yield and who will proceed. This situation is akin to the 'game of chicken,' where two drivers head towards each other at high speed; the nominal loser, termed the 'chicken,' is the first to swerve away. However, the losses are much higher if neither driver swerves, resulting in a collision.[15]

In the basic model, time, space, and velocity are discretised, as shown in Figure 1 (right). The agents are positioned on a square grid, moving at discrete speeds measured in squares per turn within a series of discrete turns. There is no provision for lateral movements (swerving), and the agents cannot communicate with each other except through their observable positions and speeds. With each turn, both vehicles simultaneously choose and execute a speed in a manner reminiscent of 'rock, paper, scissors.' The vehicles incur a time penalty for each delay in reaching their destination past the intersection,

[14]Charles Fox et al. (n 8).
[15]Variations of the game of chicken can be seen in the movies 'Rebel Without a Cause' directed by Nicholas Ray (1955), Warner Bros; and 'Back to the Future Part III' (1990) Directed by Robert Cohen, Universal Pictures.

with a more severe collision penalty applied if they collide. The collision penalty may be symmetrical for similar agents (e.g. two pedestrians or vehicles of the same type) or asymmetrical (e.g. a sport utility vehicle impacting a pedestrian or a smaller car incurring less damage than the party it hits).

The mathematical solution of this model is that the optimal strategy for both players is recursive and probabilistic.[16] At each turn, each player calculates the probability of yielding and then acts accordingly. This probability increases from zero towards – but never actually reaching – certainty as the distance between the agents decreases. The collision probability thus remains strictly greater than zero, even when it is marginally small, at all times. The probabilities are influenced by the 'strength' of each agent; for example, a sports utility vehicle has a lower yield probability compared to a pedestrian in the same encounter because it would take the least damage in the event of a collision.

Empirically, human behaviour in a simulated road-crossing scenario can be fit to this model[17] with the agent's behaviour summarisable by a single parameter. This parameter measures the individual's 'assertiveness' as the ratio of the agent's value of time (i.e. dollar value of losing 1 s of arriving at their destination, for example, by yielding to the other agent for road priority) and the agent's (negative) value of the collision actually occurring – which will be worse for a pedestrian than for an SUV. This suggests that AV controllers should try to estimate this parameter for other road users in interactions, which they can use to play the game optimally. Estimation could technically be performed based on visually observable features of pedestrians and their historical correlations with assertiveness, either at the fine-grained accuracy of recognising individuals and their interaction histories or more coarsely at the accuracy of classifying individuals into classes with averaged interaction histories. This raises legal questions about the use of personal data and stereotyping based on superficial features.

Studies have proposed enhancements to the basic model[18] and suggest that incorporating more realistic physics (continuous time, space, speed, multiple agents) does not alter the fundamental findings. They all agree that it is necessary to impose some negative utility on the other agent with strictly non-zero probability in order to advance.

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[16]Charles Fox et al. (n 8).

[17]Fanta Camara et al., '2018. Empirical Game Theory of Pedestrian Interaction for Autonomous Vehicles' *Measuring Behavior 2018: 11th International Conference on Methods and Techniques in Behavioral Research*.

[18]Fanta Camara et al., 'Towards Game Theoretic AV Controllers: Measuring Pedestrian Behaviour in Virtual Reality' (2019) *Proceedings of TCV2019: Towards Cognitive Vehicles* 7–10; Fanta Camara et al., 'Continuous Game Theory Pedestrian Modelling Method for Autonomous Vehicles' in *Human Factors in Intelligent Vehicles* (River Publishers 2022) 1–20; Yalada Rahmati et al., 'Game Theory-Based Framework for Modeling Human–Vehicle Interactions on the Road' (2020) 2674(9) *Transportation research record* 701–713; Roja Ezzati Amini, Ashish Dhamaniya, and Constantinos Antoniou, 'Towards a Game Theoretic Approach to Model Pedestrian Road Crossings' (2021) 52 *Transportation Research Procedia* 692–699.

Subsequent iterations of the model[19] demonstrated that the requirement for rare actual collisions can be supplanted by more frequent yet less severe 'small negative utility' penalties. This approach aims to enhance the safety of AVs while still allowing them to navigate effectively. For instance, such penalties could involve spraying water at misbehaving pedestrians, capturing their images to display on billboards as a public humiliation (a practice currently employed in China to penalise other antisocial highway behaviours[20]), drawing attention to their misconduct, or encroaching upon their personal space to induce discomfort without causing physical harm. The use of a horn presents a curious case – as currently employed especially by human tramdrivers for whom braking is hard and swerving is impossible – which ostensibly serves a dual function. According to the Highway Code,[21] a horn's primary role is to make one's presence known and signal potential danger. Nonetheless, horns are frequently also used when the other party is clearly already aware of the driver, to indicate disapproval of their actions. Similar to the shaming intent of the billboards in China, the secondary function is to highlight and shame the social transgressor publicly.[22]

A current option of interest for inflicting the required small negative utilities is the deliberate invasion of personal space. In psychology, proxemic zones[23] denote the personal space surrounding an individual. People typically experience discomfort when these zones are breached. Kinematic modelling[24] generates and explains these zones as physical areas where potential contact, or the threat thereof, could occur without the possibility of evasion or self-defence by the pedestrian. Thus, being in close proximity to a pedestrian necessitates a level of trust usually reserved for acquaintances rather than strangers. Consequently, encroaching on this space when standing or driving can elicit strong feelings of vulnerability and unease. Deliberately inducing discomfort in this way could be used to replace the game-theoretic need for actual collisions, so it appears to present a useful solution to the freezing robot problem. However, it still requires AVs to inflict a small form of deliberate (psychological, not physical) penalty to members of the public. By 'buzzing' close to pedestrians, it may also increase the risk of purely accidental collision.

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[19]Fanta Camara et al. (n 18).

[20]<https://www.cnet.com/news/politics/in-china-facial-recognition-public-shaming-and-control-go-hand-in-hand/>

[21]UK Highway Code, Rule 11. 'Use only while your vehicle is moving and you need to warn other road users of your presence. Never sound your horn aggressively.'

[22]Ben Jann and Elisabeth Coutts, 'Social Status and Peer-Punishment: Findings from Two Road Traffic Field Experiments' in Ben Jann and Wojtek Przepiorka (eds), *Social Dilemmas, Institutions, and the Evolution of COOPERATION* (De Gruyter 2017) 259–27.

[23]Edward T Hall, *The Hidden Dimension* (Doubleday Anchor Books 1966).

[24]Camara and Fox (n 4)'; Fanta Camara and Charles Fox, 'A Kinematic Model Generates Non-Circular Human Proxemics Zones' (2023) 37 *Advanced Robotics* 1566–1575.

3. Legal status of ADR

Autonomous vehicles span a variety of types, including large on-road self-driving cars, trucks, vans, and smaller ADRs that navigate both public and private sidewalks, footpaths, and other pedestrian-friendly zones. While this study's primary focus is on ADRs, it acknowledges that certain insights may extend to larger on-road autonomous vehicles. There is some ambiguity regarding where an ADR should legally and safely operate – whether on carriageways, pavements, pedestrian areas, cycle lanes, or in their own dedicated lanes – which remains debatable. If ADRs were to be used on footpaths, they might need a legal classification similar to pedestrians, cycles, or mobility scooters.

Highways in the UK refer to all areas which can be used by the public for movement. 'Roads' are highways which may consist of several legally distinct subareas of different legal categories. The 'carriageway' is the area for use by cars and other large vehicles. The 'pavement' is for pedestrians. There may also be cycle lanes and other regions with different usage restrictions.

Pavements in the UK have traditionally been the domain of pedestrians. Today's regulations, some of which were established in an era before the advent of ADRs, nevertheless provide a framework that can encompass these modern devices. According to Rule H2 of the Highway Code, the term 'pedestrians' includes individuals on foot and those using wheelchairs and mobility scooters, all of whom have exclusive rights to pavement use. Additionally, pedestrians are legally entitled to use parts of the road, cycle tracks, and pavements where signs do not explicitly prohibit their presence.

Footpaths are public rights of way over land, which may only be used on foot (as opposed to a bridleway, which also allows the riding of horses). Generally, mechanically propelled vehicles are forbidden from using footpaths by section 34 of the Road Traffic Act 1988,[25] and using powered transporters on the pavement is an offence. The Highway Act 1835 Section 72 (England and Wales) states that it is an offence, '… ..*If any person shall wilfully ride upon any footpath or causeway by the side of any road made or set apart for the use or accommodation of foot passengers; or shall wilfully lead or drive any horse, ass, sheep, mule, swine, or cattle or carriage of any description, or any truck or sledge, upon any such footpath or causeway; or shall tether any horse, ass, mule, swine, or cattle, on any highway, so as to suffer or permit the tethered animal to be thereon* … … … .'

Using any form of vehicle, including bicycles, on footpaths is typically not allowed unless specific signage indicates otherwise. Electric bikes, if they

[25]UK Department of Transport, 'Guidance, Powered Transporters' www.gov.uk/government/publications/powered-transporters/information-sheet-guidance-on-powered-transporters

meet specific requirements, are treated as regular bicycles under UK law and, thus, are not allowed on footpaths.

Wheelchairs and Mobility Scooters are exceptions. Both manual and powered wheelchairs and mobility scooters (classed as 'invalid carriages') are allowed on footpaths. Manual wheelchairs (Class 1) and powered wheelchairs with a speed limit of 4mph (Class 2) are designed for use on footways or pavements; and powered mobility scooters (Class 3) are allowed on the roads and pavements subject to meeting certain legal requirements, including those set by the Driver and Vehicle Licensing Agency (DVLA). The scooters must have an upper-speed limit of 4mph (6 km/h) and 8mph (12 km/h).[26] When on the road, they must obey the guidance and rules for other vehicles; and when on the pavement, they should follow the guidance and rules for pedestrians. (Rule 37) Also, pavements are safer than roads and should be used (by wheelchairs and mobility scooters) when available. However, wheelchairs and scooters should prioritise pedestrians and show consideration for other pavement users, particularly those with hearing or visual impairment who may not be aware they are there.[27] Accordingly, wheelchairs and mobility scooters cannot exceed 4mph on pavements or other pedestrian areas. Rule 13 of the Highway Code[28] acknowledges that '… some routes are shared between pedestrians, cyclists, horse riders and horse-drawn vehicles. Cyclists, horse riders and drivers of horse-drawn vehicles should respect the safety of pedestrians, but (pedestrians) should take care not to obstruct or endanger them. They (pedestrians) should always remain aware of their environment and avoid unnecessary distractions.' The Code also allows 'pedestrians' to use other parts of the road, like cycle tracks, recognises the interactions between different users of the pavement and sets out obligations for the respective users.[29]

The ADR shares some similarities with the Class 3 mobility scooters. As noted above, this category of scooters is the only type of 'invalid carriages' allowed on roads, sidewalks, pavements, footpaths, and other pedestrian areas. Like a mobility scooter, the ADR has a maximum speed of 8mph. It can also adapt to road and legal conditions specified for wheelchairs and scooters in rules 41–46 of the Highway Code. Weight specifications for the scooters are a maximum unladen weight of 150 kg or a maximum laden weight of 200 kg when carrying necessary user equipment such as medical

[26]Rule 36 Highway Code.

[27]Rule 38 Highway Code.

[28]Department of Transport 'The Highway Code' <https://www.gov.uk/guidance/the-highway-code/rules-for-pedestrians-1-to-35>

[29]The other exception made in the Highway Act 1835 is for 'mobile plant', which includes specialised vehicles such as street sweepers and grass cutters. However, 'mobile plants' are typically heavy machinery and vehicles used for construction and other related activities. It is doubtful that ADRs would fit this classification, given the vastly different purposes and the potential hazards of mobile plants on footpaths.

supplies.[30] Mobility scooters must have direction indicators that are able to operate as a hazard warning sign, audible horn, and amber flashing light if used on a dual carriageway. They must follow the Highway Code if driving on the road.[31] Although they must be registered, mobility scooters are exempted from tax, and insurance is recommended but not mandatory. More importantly, while the code prioritises pedestrians over scooters on the pavement, it also requires mutual respect and consideration among users. The same standards and expectations will presumably apply if the ADR uses the pavement. While it is still a grey area, a legal basis exists for allowing ADRs to manoeuvre on pavements, footpaths, and carriageways without changing the law.

It is also possible to classify ADRs as 'pedestrians.'[32] This would require legal reform that expressly designates them as pedestrians, as some states in the US have done. Under Pennsylvanian law, delivery robots are technically pedestrians with access to both roads and pedestrian paths.[33] The robots can carry up to 550 pounds of cargo at speeds of up to 25 miles per hour on roadways but must cap their speed at 12 miles per hour in human – presumably – pedestrian areas.[34] Any regulation will need to account for a wide range of safety considerations. Robot delivery vehicles should be kept off the roadway except when crossing at a zebra crossing or something similar.[35]

Social acceptance, including the increasing tendency to anthropomorphise the ADR, makes a compelling case for law reform. During ADR trials in the UK, people's responses ranged from awe to curiosity. ADRs (Starship Technologies robots) were described as 'cute' and locals in Cambridge were said to be resisting the temptation to 'stick googly eyes on them.' One woman reportedly said: 'My dog loves them; he thinks they're dogs in disguise.'[36] Others assumed the robots needed help or

[30]Using Mobility Scooters and Powered Wheelchairs <https://www.gov.uk/mobility-scooters-and-powered-wheelchairs-rules>

[31]Ibid.

[32]In early 2020, the International Organization for Standardization (ISO) launched an Intelligent Transport Systems project called 'Sidewalk and kerb operations for automated vehicles.' ISO/4448 contains over 120 data definitions on weight, size, speed and cybersecurity, as well as more nuanced guidance on the direction of travel, the desirable shy distance between the robot and pedestrians (both walking and standing), and the lights. It makes sounds to alert deaf and blind people to its presence and scheduling systems for multiple deliveries. The work is still ongoing <https://cities-today.com/new-standards-on-the-way-for-delivery-robots/>

[33]E.g. Virginia, Idaho, Florida, Wisconsin and Washington DC all have laws that permit delivery robots to share pedestrian spaces.

[34]Vehicle Code (75 PA C.S) Personal Delivery Devices and Making Editorial Changes (Pennsylvania General Assembly 2020 Act 106 SB 1199) <https://www.legis.state.pa.us/cfdocs/legis/li/uconsCheck.cfm?yr=2020&sessInd=0&act=106>

[35]EU-ICIP Guide '13 Kerbside Ground Based Automated Mobility' <https://www.mobilityits.eu/kerbside-management>

[36]Eirian Jane Prosser, 'Pictured: Delivery Robots Queue Patiently to Use Pedestrian Crossing in Cambridge- as One asks Woman Passing by to Press the Button for them (Mail Online 3 December

could be played with, 'they look so sad waiting on the kerb' and 'they don't really have the ability to press the big buttons.'[37] We can generally interpret these responses as playfulness, or intention to help or, touch, or lift the robots or, more generally, absence of fear or apprehension from pedestrians or as a readiness to recognise them as co-users of pavements and pathways. This also recognises the robots as social agents/actors rooted in social or philosophical interpretations of autonomy, if not the legal interpretation.[38]

This does not suggest that classifying the ADR as a pedestrian is without challenges. ADRs can impact access to car-free road space, constituting an obstruction to other (e.g. human) pedestrians' right of way. This may particularly affect wheelchair users and deaf or visually impaired pedestrians. A fleet of robots could cause noise pollution and be deemed a nuisance if they also obstruct pedestrians and make walking difficult. A pavement is a public space shared by many users, including residents, vendors, visitors, and shoppers, whether able-bodied or not. Any conflict that causes bodily harm, property damage, financial loss, or other real or perceived harm may be subject to legal action. Hence, a shared understanding and description of these spaces is necessary to determine the correct use and assign liability for legal and insurance purposes.[39]

4. Wrongful interferences and justification for 'small penalties'

The game theoretic model suggests that it is necessary to impose some negative utility on the other agent with strictly non-zero probability in order for the AV to advance. While the threat of actual collision is one such negative utility, the model also shows that smaller, less dangerous negative utilities (penalties) could be used to achieve efficient interaction of the ADR with pedestrians.

Naively, it would make sense for the robot to always yield the right of way (the Pennsylvania law even makes this a legal requirement)[40] to pedestrians. UK law expresses this assumption. Regarding cyclists, for example, the Highway Code states that in some cases, cycle tracks will be shared with pedestrians, 'On such shared use routes, you (the cyclist) should always take care when passing pedestrians, especially children, older or disabled people, and

2022) <https://www.dailymail.co.uk/sciencetech/article-11497909/Pictured-Delivery-robots-queue-patiently-use-pedestrian-crossing-Cambridge.html>

[37]BBC, Cambridge Delivery Robots Form Orderly Queues at Traffic Lights (2 December 2022) <https://www.bbc.com/news/uk-england-cambridgeshire-63821535>

[38]E.g. Thomas Khurana 'Paradoxes of Autonomy: On the Dialectics of Freedom and Normativity' (2013) 17 (1) *Symposium* 50–74 <https://doi.org/10.5840/symposium 20131714>

[39]Harmonize Mobility, The Last Block: Towards an International Standard to Regulate and Manage Sidewalk Robots <https://harmonizemobility.com/wp-content/uploads/2021/05/Harmonize-Mobility-White-Paper-final-update_26Jan.pdf>

[40]House Committee on Appropriation 'Fiscal Note' Senate Bill No. 1199, <https://www.legis.state.pa.us/WU01/LI/BI/FN/2019/0/SB1199P2042.pdf>

allow them plenty of room. Always be prepared to slow down and stop if necessary.'[41] The Rules also contain instances where other users, including cyclists and horse riders, must defer to pedestrians.[42] We must assume that the same rules will bind the robot in these instances. However, suppose another agent (a pedestrian) could always assume priority, anticipating that the ADR would consistently yield (the freezing robot problem). In such cases, it becomes a practical requirement for the ADR to be able to deter this behaviour by not always yielding to humans. If ADR were always to yield the right of way, this would create learned human behaviours with implications for the effective functioning of the ADR. For example, pedestrians continually pushing in front of an ADR may lead to delays and late deliveries, increased operational costs, and loss of profits to user organisations. This may also compromise the quality of the cargo. In some cases, this could be life-threatening to other humans, such as cargo recipients waiting for urgent medical delivery. It may, therefore, be necessary to consider other forms of deterrence, which may include a warning (for example, if a pedestrian is moving too close) and a means of ensuring the robot can assert its right of way without introducing new or more significant risks and with due regard for the rights of other users with which it shares the road.

Clearly, if a pedestrian deliberately obstructs the ADR, there might be potential legal consequences. In some cases, it may be possible to analogise to emergency services to deter physical interference. Emergency service workers, such as paramedics, can navigate through crowds, and people usually yield due to the urgency of the situation. ADRs could be granted similar 'rights of way,' especially when delivering critical cargo like urgent medical supplies. ADRs could use sirens and lights to indicate urgency. They could also be equipped with lights and sounds that activate under certain circumstances. An audible alert could warn individuals if they are too close or if the ADR detects potential interference. This could be a simple beep or a voice alert saying, 'Please stand clear,' as currently used in some large reversing human-driven vehicles.

The above will, however, only work in limited cases relating to critical cargo and not in other circumstances when the ADR's operations might be disrupted by the freezing robot problem, as a learned behaviour, causing the ADR always to yield the right of way to other pedestrians. In such cases, it seems reasonable to allow the model to deliver small penalties, like continuous horn noises and squirting water at pedestrians, to deter attacks, theft and other interferences or abuses that affect effective and

[41] Rule 62 Highway Code.
[42] Rule H2.

timely functioning. The question is whether it is lawful to programme the model to behave this way.

We argue that the penalties proposed here do not differ significantly from warnings or other behaviours permitted for other road users. For example, drivers and riders can use the horn while their vehicle is moving and must warn other road users of their presence. They can flash their headlights to let other road users know they are there.[43] Cyclists are required by Rule 63 of the Highway Code to ring the bell or call out politely when riding in places where sharing with pedestrians, horse riders or horse-drawn vehicles is permitted. Admittedly, this does not mean that the lines between acceptable and unacceptable behaviours for warning or deterrence are clear. For instance, revving and edging forward by a motorist when pedestrians are crossing is deemed harassment. As rule 194 provides, 'Allow pedestrians plenty of time to cross and do not harass them by revving your engine or edging forward.' Also, you should 'only flash your headlights to let other road users know you are there. Do not flash your headlights to convey any other message or to intimidate other road users.'[44] Following these examples, the ADR can honk or flash its light to indicate that it is on the road, and another user refuses to yield or intentionally obstructs it. However, we also assume that the robot can 'sense' its environment and anticipate an attack or a repeat attack, such as when another user advances at an unreasonable or excessive speed that may lead to a collision or a pedestrian repeatedly kicks or knocks over the ADR. In these cases, the robot is also programmed to administer small penalties in response to these specific 'bad' behaviours and to avoid or minimise the collision.

It is tempting to propose a bespoke law designed to address the unique challenges posed by the freezing robot. However, a flexible and adaptable interpretation is beneficial for integrating the new circumstances and realities of ADR into existing traffic laws. Using these preexisting or 'inherited regulations' is a common strategy to address the 'pacing problem' – the gap between introducing new technology and establishing relevant laws, regulations, and oversight mechanisms.[45] By relying on inherited traffic regulation, regulators can quickly act to prevent harm and even promote innovation. This approach has enabled regulators to issue guidance on autonomous vehicles under existing traffic rules without needing specific authority over the technology.[46] It follows that as traditional automobile safety regulations already address multiple problems and the pathways

[43](Rules 110, 111, 112).

[44](Rule 110).

[45]Walter G Johnson and Lucille M Tournas, 'The Major Questions Doctrine and the Threat to Regulating Emerging Technologies' (2023) 39 *Santa Clara High Tech. L.J.* 137, 140; Ryan Hagemann, Jennifer Huddleston Skees, and Adam Thierer, 'Soft Law for Hard Problems: The Governance of Emerging Technologies in an Uncertain Future' (2018) *Colo. Tech L.J* 59.

[46]<https://www.transportation.gov/sites/dot.gov/files/docs/AV%20policy%20guidance%20PDF.pdf>

leading to vehicle accidents, such as driver errors, vehicle malfunctions, roadway hazards, and interpersonal and bad behaviours, the usual responses to these problems and their pathways should be adapted to the freezing robot problem, or at least allowed to fully evolve before enacting new laws.[47]

Explaining the pathways-related approach to regulation, Coglianese argues that they require regulators to identify the causes of regulatory problems and then impose rules to impede these causal pathways. However, it is more feasible to identify causal pathways when a technology is stable or has been around for a long time. For new technologies, regulators will need to learn more and identify the causal pathways to target with new regulations.[48] However, if, at a minimum, regulators can define a problem clearly or know that it has arisen and caused harm, they can be deemed to have an understanding of the causes of problems. They can, therefore, identify major pathways leading to the problems and impose and monitor compliance with rules demanding actions or results aimed at blocking those pathways. In the case of new technology, regulatory strategies that mandate action or results along specific pathways, like the freezing robot problems, may be less appealing because these pathways are still being understood and are likely to change as technology evolves. Moreover, excessive interference in the pathways may risk stifling technological innovation, which could have negative effects[49] as they often fail to solve the pacing problem.

Although new or bespoke laws hardly solve the pacing problem, they do not lack merit. Indeed, ADRs have unique characteristics and operational requirements, such as their use in pedestrian areas and interactions with people and other environmental actors, which may justify a new law. Additionally, there is no guarantee that courts will support an extended interpretation or expansion of the law to include the ADR as a pedestrian. Using old legislation for new technologies might allow product manufacturers to claim immunity, arguing that the laws were not designed for their specific technology, similar to claims of immunity under Section 230 of the Communications Decency Act 1996 by social media companies. They may create a situation where regulators issue subsidiary legislation that requires thorough debates unilaterally using broad powers granted under their enabling laws.

This dilemma has prompted discussions about alternative and more flexible regulatory regimes to cope with the pacing problem, with proposals to replace traditional regulatory models like hard laws with soft laws and

[47] e.g. Cary Coglianese, 'Regulating New Tech: Problems, Pathways, and People' (2021) *All Faculty Scholarship* 2753 <https://scholarship.law.upenn.edu/faculty_scholarship/2753>

[48] Ibid., at 7.

[49] Ibid., at 6.

techno-regulation (regulation by technology).[50] As Hagemann et al. suggest, the overriding question is whether current rules or inherited regulations can provide adequate coverage, fit, or policy outcomes and whether they possess the appropriate values, goals, and tools to manage the innovations at hand. Only when these criteria are not met should policymakers consider enacting new laws or establishing novel regulatory frameworks.[51] In the section below, we explore 'robot self-defence' and the defence of property as justifications for inflicting small penalties.

4.1. Legal basis for inflicting penalties: robot self-defence

The concept of robot self-defence is inspired by the right to self-defence for humans in various legal systems. In this context, it refers to the ADR's ability to protect itself from harm, abuse, or interference by other road users. ADRs may deter such behaviour and operate more effectively by maintaining a credible threat of inflicting small penalties on pedestrians who impede their progress or deliberately interfere with their operation.

In criminal law, self-defence means countering an attack or imminent attack to defend oneself against harm. Self-defence is the apprehension of immediate and unlawful violence. Generally, it covers the use of force to prevent an imminent attack. Revenge or retaliation cannot qualify as self-defence (as they occur after the fact or when the event has already occurred). Self-defence is both a common law and a statutory defence. At common law, a person is permitted to use reasonable force to defend himself from attack, prevent an attack on another person or defend his property. The conditions for invoking the statutory defence are slightly different. Statutory self-defence is covered by the defences provided in section 3(1) of the Criminal Law Act 1967 (the use of force to prevent crime or make an arrest). The section provides, 'A person may use such force as is reasonable in the circumstances in the prevention of crime, or in effecting or assisting in the lawful arrest of offenders or suspected offenders or of persons unlawfully at large.' While the section does not expressly mention self-defence, the plea is available to prevent crimes, including crimes against a person. Section 76 of the Criminal Justice and Immigration Act 2008 provides further clarification. This section applies where, in the proceedings for an offence, an issue arises whether a person (the defendant) charged with the offence is entitled to rely on the defences in section 76(2) of the Act. The question arises whether the degree of force used against a person

[50] Hagemann et al (n 45) at 60; Roger Brownsword and Han Somsen, 'Law, Innovation and Technology: Before We Fast Forward—A Forum for Debate' (2009) 1 *LIT* 1.

[51] Johnson et al (n 45) at 160.

(the victim) was reasonable in the circumstances. The defences covered by section 76(2) are the common law defence of self-defence, the common law defence of property and the defences provided by section 3(1) of the Criminal Law Act 1967. Self-defence is founded in the rationale that it is both good law and good sense that a man who is attacked may defend himself. Force can be used in self-defence, defence of another, defence of property, to prevent crime or to assist a lawful arrest. Self-defence is an absolute defence, meaning a person can avoid a criminal charge if it is successfully pleaded. However, given the circumstances, the force must be necessary and reasonable (and not excessive).

The following sections examine whether and how the ADR can meet the criteria for self-defence as a justification for inflicting small penalties. It argues that either the small penalties do not qualify as a force to warrant invoking self-defence or that the force or small penalties are justified in the circumstances.

4.1.1. Do small penalties constitute the use of force?

It is doubtful whether we can classify the small penalties inflicted by the robot as 'force' which may give rise to charges of assault, battery, or other related crimes. It is only if such charges can be made that the robot can invoke self-defence in the first place, particularly since the courts appear to make a distinction between the use of force and actions that are 'less than using force.' In *Blake*,[52] the court suggested that actions which are less serious than using force may be excused. The defendant (a vicar) had used a felt-tip pen to write a bible verse on a pillar next to the Parliament building. He argued that he was obeying God's command to prevent the Iraq war and relied on section 3(1) of the Criminal Law Act 1967 (the use of force to prevent crime or make an arrest). Although the court held that the defence was not a lawful excuse for the criminal charge, it also held that the writing did not involve using force; therefore, the defence was not available to the defendant. Applying the same logic, we can argue that the small penalties proposed here do not really constitute the 'use of force.' Classifying honking or squirting water to deter a pedestrian who refuses to yield a right of way or obstructs, repeatedly kicks the robots or attempts to remove its cargo as 'use of force' may stretch the legal meaning of the 'use of force.'

4.1.2. Necessary and reasonable force

Assuming the courts hold that the small penalties administered by the model qualify as the use of force, the further requirement is that the force must be necessary and reasonable. The court justifies these types of force: 'It is both good law and good sense that a man who is attacked may defend himself.

[52]*Blake v DPP* (1993) Crim Lr 586.

[But] It is [also] both good law and good sense that he may do, but only do, what is reasonably necessary.'[53] The use of force covers anticipated attacks, such as when the ADR senses an attack based on the speed at which another road user travels. According to the courts, no rule in the law requires that a person wait to be struck before they may defend themselves.[54]

Although it is no longer a legal requirement, it is probably a persuasive argument that the use of force by the ADR is necessary because it would otherwise be helpless against the assailant and cannot retreat. 'If an accused has a physical handicap such that he might not be able to escape a threatened attack which an able-bodied person might be able to escape from can be taken into account by a court when considering the reasonableness of the accused's actions.'[55]

Furthermore, section 76(1) Criminal Justice and Immigration Act (CJIA) 2008 provides that '[T]he question whether the degree of force used by D [the defendant] was reasonable in the circumstances is to be decided by reference to the circumstances as D believed them to be, … ' Therefore, reasonable 'force' must be commensurate with the threat or attack. Stabbing someone with a knife when they only shoved the defendant is an unreasonable use of force in self-defence. In the case of the ADR, the question of whether the force is reasonable is further simplified by the fact that the small penalties are anticipated to cause minor inconveniences and only to prevent the robot from being rendered ineffective (freezing robot problem) due to deliberate obstruction of its right of way or for serious attacks like repeated kicking, knocking over or taking. It is not expected that the model will use (or be able to use) force that could cause death or serious injuries. As the law generally values life over property, the model will not be expected to justify the administration of penalties that cause death or serious injuries.

4.1.3. Robot personhood

Perhaps the legal status of the robot is the most challenging aspect of the robot's self-defence. Self-defence is available for offences against the person, including assault and assault occasioning bodily harm. By its phrasing, the law contemplates that humans, not machines, will claim self-defence. Therefore, the robot, being a machine, may not claim self-defence. However, social and legal developments suggest that availing robots' self-defence may not be far-fetched. As noted above, people increasingly recognise robots as social actors and tend to anthropomorphise ADRs. They vest ADRs with emotions and empathise with them. In fact, researchers tested the notion

[53]See *Palmer v R* [1971] AC 814; approved in *R v McInnes* 55 Cr App R 551.
[54]*See* R v Deana 2 Cr App R 75.
[55]British Self-defence, Law Relating to Self-defence <https://www.bsdgb.co.uk/information/law-relating-to-self-defence/>

of robot self-defence through a user survey with 304 participants, who watched eight animated videos of robots and humans in a violent altercation. The results indicated that people largely accept that a humanoid robot can use force on attackers to help others.[56] Some countries have treated robots as legal entities or vested them with legal responsibilities. A robot was arrested for buying drugs in Switzerland, and the Kingdom of Saudi Arabia granted 'Sophia,' a humanoid robot, citizenship.[57]

Also, it seems that humans can invoke self-defence against the robot and decide what level of 'force' is applicable when they (humans) are attacked or apprehend attacks from a robot. Froomkin argues that when robots pose a threat, people must disable or destroy them in self-defence.[58] They must decide 'If it (the robot) were threatening an adult or a child, what level of violence would be covered by a self-defence argument? A firm, debilitating slap or a parts-mangling rain of blows?'[59] Thus, if the attack or abuse would be a crime (such as assault or battery) if committed against a person, and the model is recognised as a pedestrian, or at least a social actor by humans, allowing them to be abused without availing them of the same defence available to humans, may not only encourage bad behaviour against the robot but also against humans.[60]

More importantly, developments in the UK could confer some legal status on robots, at least by proxy. In law, a person can be a natural or juristic person. A juristic person is an entity recognised as having a legal personality, such as a corporation. Like natural persons or individuals, legal or juristic persons can be held criminally liable if a directing mind and will (DMW) has been involved in the crime. Corporations can also sue for crimes committed against them and defend themselves against criminal charges. The Law Commission proposes an approach that could remedy the lack of legal personhood for robots by distinguishing between user-in-charge and no-user-in-charge (NUIC) vehicles. According to the Commission, whereas for user-in-charge vehicles, a human driver is in the vehicle and will be liable for accidents occurring while he is driving, even if it relates to driving in response to a transition demand, in no-user-in-charge (NUIC) vehicles, there is no human driver (to punish). The Commission then proposes a NUIC regulator scheme under which a licensed operator

[56] Eduardo Kochenborger Duarte, 'Robot Self-defense: Robots Can Use Force on Human Attackers to Defend Victims' (2022) *31st IEEE International Conference on Robot and Human Interactive Communication* (RO-MAN).

[57] 'Saudi Arabia Grants Robot Citizenship' <https://www.dw.com/en/saudi-arabia-grants-citizenship-to-robot-sophia/a-41150856>

[58] A Michael Froomkin and P Zak Colangelo, 'Self-Defense Against Robots and Drones' (2015) 48 *Conn. L. Rev*. 1.

[59] 'Can I Terminate an Out-of-control Robot?' *Financial Times* <https://www.ft.com/content/2d54ed5b-0232-4801-84b2-6fc103d3e3ab>

[60] Christoph Bartneck and Merel Keijsers, 'The Morality of Abusing a Robot' (2020) 11 *Paladyn, Journal of Behavioral Robotics* 271–83 <https://doi.org/10.1515/pjbr-2020-0017>

should supervise and maintain all NUIC vehicles. The requirement will apply whether the vehicle provides passenger or freight services or is for private use. The ADR will certainly need an NUIC operator under the proposed regulatory scheme. A user-in-charge must always be 'an individual,' a human or a 'natural person' rather than a system or organisation.[61] The NUIC operator will be licensed to oversee the ADR, have responsibilities for dealing with incidents and (in most cases) for insuring and maintaining the vehicle. Since the robot is not 'a person' in the sense of being conscious or having a personality or self-awareness for decision-making, the operator could probably be treated as the DMW of the ADR for the purpose of legal personhood or held responsible if the plea of self-defence fails. This is more so because evaluating the necessity to use force and the type and amount of reasonable force are all pre-coded by (human) designers.

4.1.4. Mistake and incapacity

Other possible cases where self-defence may be problematic include mistakes and incapacity. For example, algorithmic predictions and judgement may fail, causing the ADR to misjudge that an attack will take place. The robot may misinterpret or misapprehend the situation and administer punishment when it is unwarranted. Also, the 'assailant or would-be assailant' could be a person who cannot be held criminally responsible, such as a child or other persons otherwise lacking criminal capacity. While self-defence is available even if a person is mistaken about whether they were being attacked,[62] escaping criminal liability on the grounds of self-defence does not preclude civil liability in the tort of negligence for the same act.[63] In other words, even if the plea of self-defence succeeds, children or other criminally incapacitated persons needlessly or unjustifiably 'penalised' by the robot can seek damages for negligence in a civil court.[64] The points are discussed further under liability for accidents in section 5.

4.2. Legal basis for inflicting penalties: defence of property

The concept of property rights provides another legal rationale for ADRs to impose minor penalties on pedestrians. Given that ADRs are charged with the transportation of goods that may be valuable or sensitive, they possess a vested interest in safeguarding their cargo. Should a pedestrian wilfully disrupt an ADR's functionality, the robot may be warranted to levy a

[61]Law Commission and Scottish Law Commission, *Automated Vehicles: Joint Report* (Law Commission No 404; Scottish Law Commission No 258) (2022) para 8.10.

[62]See section 76(4)-(7) of the Criminal Justice and Immigration Act 2008; see also *R v Williams (Gladstone)* [1987] 3 All ER.

[63]See *Revill v Newbery* [1996] 2 WLR 239.

[64]See further notes on negligence below.

minimal penalty as a measure to defend the property under its guardianship. This recourse to impose penalties is an extension of the right to protect property, akin to the principle of self-defence. Legally, any act of aggression towards property constitutes a criminal offence, and the property owner is entitled to exert reasonable force to thwart such attacks. The Criminal Damage Act (CDA) 1971 clearly stipulates that it is a crime to knowingly damage or destroy property or even to intend or threaten such actions without a lawful reason. This applies when awareness or recklessness regarding the potential for property damage establishes the offence's culpability.[65] Property under the Act means property of a tangible nature, whether real or personal. The property includes the money and wild creatures which have been tamed or are ordinarily kept in captivity, and any other wild creatures or their carcasses that have been reduced into possession which have not been lost or abandoned or are in the course of being reduced into possession.[66]

The CDA does not define damage; however, the courts have held that damage is a question of fact and degree. Thus, 'damage' has a wide and liberal meaning. It includes permanent and temporary physical harm and permanent or temporary impairment of the value or usefulness of the property.[67] In *Gayford v Choulder*,[68] the court held that trampling down grass or other types of vegetation may constitute damage. In *R v Whiteley*[69] smearing mud on the walls of a police cell was held to be damage. By the same logic, repeatedly kicking the ADR or obstructing its right of way could amount to damage in the sense that such acts temporarily impair its usefulness.

While it may seem that the owner (of the property) must himself act to defend the property, there are instances when the property may 'act' or be made to act to 'defend' itself. Apt analogies here include dogs that might bite when threatened or abused or guard dogs trained to defend the owner or his property. Another example is using an electric fence to administer shocks to deter intruders. In this sense, programming the robot to squirt water or honk loudly is similar to other activities to protect property rights. Based on the law, it does not matter that the model pre-empts the interference or obstruction or attack or that it would cause temporary or permanent damage. In *AG's Reference (No 2 of 1983)*,[70] a defendant who manufactured ten petrol bombs to defend his shop during the Toxteth Riots could set up the defence of property as a lawful purpose for possessing an explosive substance. The court would allow the defence if the defendant

[65]S 1(1)-(3) CDA.
[66]S 10 (1)-(2) CDA.
[67]CPS, 'Criminal Damage' <https://www.cps.gov.uk/legal-guidance/criminal-damage>
[68][1898] 1 QB 316.
[69][1991] 93 Crim. App. R. 25.
[70](1984) 1 AER 988.

could show that he reasonably believed this means was necessary to meet the attack and acted to protect himself or his family or property. Although the defence of property cannot reasonably provide a justification for inflicting serious injury, it is unlikely that the model will inflict serious injury to make the defence inapplicable. Concerning ownership, the law is that property belongs to any person having custody or control of it or any proprietary right or interest in it or having a charge on it.[71] Therefore, the NUIC operator (who must be a natural or legal person) could be designated 'owner' of the property if the Law Commission's proposal is accepted.[72] Without a designated NUIC operator or if the Law Commission's proposal is not accepted, ownership could revert to the entity responsible for deploying the ADR, such as the company or organisation that owns and operates the system. They would be responsible for the robot's actions and any potential liabilities.

5. Liability framework for ADR accidents

In the original form of the game theory model, maintaining a small but non-zero probability of a collision in both agents' strategies is essential for the interaction to optimise. While it is very rarely actualised, this slight chance of a collision acts as a deterrent; its possibility is sufficient to influence the other party's behaviour. Alternatively, later versions of the model show how non-contact invasion of personal space can create smaller penalties. However, these invasions require very accurate control, in which technical errors could lead to actual collision. This type of collision would be different from a threatened and planned collision because it is an unintended accident.

These dynamics mirror the actions of human drivers in similar situations: they often adopt aggressive driving behaviours to imply the risk of a collision and/or to pressure personal space, encouraging the other (typically misbehaving) road user to yield. Exactly like these human drivers, the ADR might accidentally collide with pedestrians or other road users due to a small control error when intending only to intimidate with a 'close call.' Instances where the algorithms make imprecise or incorrect predictions, thus inflicting small penalties in error, can also be classified as accidents and lead to claims for compensation. For example, an ADR might use its best probabilistic reasoning to predict that a pedestrian intends to cross its path, so initiate a personal space invasion or other small penalty when the pedestrian actually has other intentions and perceives the penalty as unexpected and unjustified.

We argue in the following sections that liability for 'accidental collisions' and other scenarios above are either covered by the tort of negligence

[71] Section 10(2).
[72] See 4.1.3 on Robot Personhood.

or product liability laws or could be addressed by proposed changes to the law.

5.1. Action in negligence

An individual injured by an ADR, as described in the scenarios above, may file a claim for negligence. Negligence, a civil wrongdoing, arises from loss or harm caused to another due to a breach of duty of care, particularly when products are employed in anticipated ways. The criteria for a negligence claim include an established duty of care by the defendant towards the claimant, a breach of that duty, the claimant sustaining injury or damages, and the injury or damage being a predictable result of the breach. In the case of accidents, the human driver typically holds the primary responsibility. However, they may be entitled to indemnification by their insurance or may face diminished liability if the claimant's own negligence contributed to the incident. Consequently, a driver who operates their vehicle without proper consideration or care for others on the road, driving recklessly, or without a valid licence could be held accountable for any accidents resulting from such conduct.

ADRs present different challenges because no one drives them. However, the Automated and Electric Vehicles (AEV) Act 2018 applies relevant provisions to ADRs. Section 2 of the Act provides that the insurer is liable for accidents caused by an AV when driving on a road or other public place in Great Britain, and an insured person or any other person suffers damage because of the accident. The vehicle must be insured at the time of the accident. 'Damage' for the purpose of the law means death or personal injury, and any damage to property other than the AV itself, goods carried for reward and property in the custody of the insured person or person in charge of the vehicle.[73] The law also makes provisions for contributory negligence. Section 3 of the Act limits liability when the accident or the damage resulting from it was caused to any extent by the injured party. Liability regarding damage to property caused by any one accident involving an AV is limited to the amount specified in section 145(4)(b) of the Road Traffic Act 1988.[74] However, the insurer or owner of an AV is not liable at all or bears reduced liability for accidents resulting from unauthorised software alterations or failures to update software or install safety-critical software updates that the insured person knows, or ought reasonably to know, are safety-critical. 'Software alterations' and 'software updates,' in relation to AVs mean (respectively) alterations and updates to the vehicle's software.

[73] S 3 AEV Act.
[74] S 2(4) AEV Act.

In contrast, software updates are 'safety-critical' if it would be unsafe to use the vehicle in question without the updates being installed.[75]

Although it is improbable that the ADR would cause or be involved in serious or fatal accidents – since the small penalties are expected to cause only inconvenience, embarrassment, or discomfort to deter bad behaviours – this possibility cannot be entirely ruled out due to the high pedestrian traffic on pavements. The AEV Act does specify how liability for serious dynamic driving offences, such as manslaughter, will be allocated. However, with no human driver to 'punish,' the Law Commission's proposal that autonomous vehicles (AVs) shift from a fault-based accident regime and the criminal enforcement of traffic rules towards a new no-blame safety culture may address this gap (of no human to blame) for ADRs. This new regime will include the introduction of *new safety assurance regulations* involving initial authorisation (before vehicles are brought to market) and an in-use safety scheme (ensuring that the vehicles remain safe while in use). The manufacturer or developer putting the vehicle forward for authorisation will need to submit a safety case demonstrating that the threshold for self-driving is met. This entity will also need to show that it can keep the vehicle safe continuously. If it qualifies, the entity will be registered as an Authorised Self-Driving Entity (or ASDE) and subject to regulatory sanctions if things go wrong.[76]

A new AV in-use regulator will have statutory duties and powers to apply a wide range of regulatory sanctions, including civil penalties, improvement notices and (where necessary) suspension of authorisation if an authorised AV breaches traffic rules while driving. The objective here is to emphasise a learning culture that prevents recurring problems. The Law Commission further proposed a new approach to dynamic and non-dynamic driving offences under which the NUIC will no longer be subject to dynamic driving offences such as over-speeding but will continue to be liable for non-dynamic driving offences such as failing to carry insurance or using the vehicle in a dangerous condition.[77]

New offences will be created to strike the correct balance between promoting innovation and filling the gaps for offences like (corporate) manslaughter and promote a no-blame safety culture that enables AVs to learn from mistakes.[78] The new offences include failure of the applicant (for an NUIC operator licence) to provide information to the regulator or providing information that is false or misleading in a material way where that information is relevant to the evaluation of the safety of the operation. The NUIC operator would have a defence if it could show that it took reasonable precautions and

[75]S 4(6) AEV Act.
[76]Law Commission (n 61), paras 1.23(1)(a)–(b) – 1.29.
[77]Ibid. para 9.133.
[78]Ibid., para 11.1.

exercised all due diligence to prevent wrongdoing. Another offence involves failure (of the NUIC) to provide information upon request by the regulator or providing false or misleading information for either pre-deployment of in-use safety where that information is relevant to the evaluation of the safety of the vehicle or the way that it operates. A senior manager who plays a significant role in deciding how the NUIC is managed or organised or safety assurance processes may also be guilty of an offence of consenting or conniving if the NUIC is guilty of an offence. A person who signed a relevant safety case or response to information (to be called 'the nominated person') could also commit an offence if the NUIC/ASDE is deemed to have committed an offence. The offences are aggravated if they cause death or serious injury.[79] These provisions will likely apply to the ADR in cases where wrong or inaccurate algorithmic predictions lead to serious injuries which are not anticipated.

5.2. Product defect

Liability for product defects in the UK is governed by the General Product Safety Regulations (GPSR) 2005 and the Consumer Protection Act (CPA) 1987. Although the law does not provide a list or outline of products, the product presumably includes vehicles. Under the CPA, 'product' includes any goods or electricity and includes a product contained in another product as a component or a raw material.[80] The CPA imposes strict liability for defective products.[81] A product is defective if the safety of the product is not such as persons generally are entitled to expect, considering all the circumstances, including the way and the purpose for which the product has been marketed, any mark used in relation to the product or its instructions for use or warnings, what might reasonably be expected to be done with or in relation to the product, and when the product was supplied (that is, a product is not defective just because a safer product was subsequently developed or introduced into the market).[82] The courts have determined that a defect is an abnormal potential for harm – in other words, something about the condition or character of the product that elevates the underlying risk beyond the level of safety that the public is entitled to expect from a product of that type.[83] The product's reasonable expected use and the time

[79]Ibid., Rec 65, para 11.86.
[80]s 1(2)(c) CPA.
[81]Strict liability means people injured by defective products can sue for compensation without proving the manufacturer's negligence (Liability without fault). Liability cannot be excluded or limited by contract and is joint and several. Joint and several liabilities mean the person harmed by a defective product can sue multiple parties and recover full damages from one or all. Manufacturers, designers, producers, and importers can be held liable. Suppliers are not liable if they can identify the manufacturer or producer of the defective product.
[82]S 3 (1) and 3(2) CPA.

it was put into the market are relevant in determining its 'defect.' Thus, the model may be deemed defective due to manufacturing and design defects, failure to warn, software glitches, such as failing to avoid a collision that later analysis shows was preventable, or flawed algorithms that lead to incorrect/inaccurate decisions about threats and the infliction of small penalties.

Liability under the CPA can rest with the producer, manufacturer, or product importer into the UK.[84] Product liability cannot be excluded by contract.[85] However, the fact that a safer product became subsequently available will be deemed irrelevant if, given the technical and scientific knowledge level, the model could not have been made safer when it was introduced into the market. All that is required is that the safety standard corresponds to state of the art in scientific or technological knowledge at the appropriate time. It is, therefore, a defence under the CPA that the state of scientific or technical knowledge at the relevant time is such that the manufacturer could not have known the defect in the product. In cases where the ADR inflicts small penalties due to incorrect or inaccurate algorithmic predictions or decisions, it would not be deemed defective simply because algorithms that could have made more accurate decisions subsequently became available. Other defences to a product defect claim are that the manufacturer (or designer) cannot *reasonably* be expected to discover the safety fault or that the safety fault was an inevitable result of obeying the law or regulatory compliance. For example, the model could be safer but for provisions of the law which exclude the use of a particular technology.

A necessary means to avoid liability for product defects is by providing a warning.[86] Therefore, the model must carry a warning that it could inflict penalties if other users interfere with its operations. Nevertheless, product liability law may have limited application and is unlikely to play a significant role in AVs (or ADRs) for specific reasons. These include the fact that individuals are unlikely to purchase or use an ADR, claims under the product liability regime are costly, and they have a poor success rate; moreover, the CPA is more likely to be used by insurers to bring claims against the manufacturers considering the provisions of section 2 of the Automated and Electric Vehicles Act 2018. Finally, it may be challenging to establish defects in AI-powered products like the ADR because opaque algorithms make it difficult to show whether the software is defective or caused the incident complained of.[87]

[83] *Colin Gee and others v. DePuy International Ltd* [2018] EWHC 1208 (QB) at 112; see also *Wilkes v DePuy* [2016] EWHC 3096 (QB) considered the determination of a defect in a product and provided guidance for understanding section 3 of the Consumer Protection Act.
[84] s 1(2), 2(2) CPA as amended.
[85] see s 7 CPA.
[86] see s 3 CPA 1987.
[87] See Law Commission (n 61), para 13.25.

6. Interaction control using personal information

Optimal game-theoretic negotiation with pedestrians requires an ADR to make inferences about the pedestrians' own utilities – in particular, with regard to the parameter which measures how the pedestrian values their time against the utility and risk of collision or of small penalties. Other useful inferences could include the probable destination of the pedestrian, which can be used to predict their long-term trajectory, and the probability of them engaging in distractions (such as phone use) or trying to steal or damage the ADR.

Machine learning algorithms can make different predictions about individuals' probable future behaviours based on whatever superficial data is available. An ADR does not typically have access to the underlying psychological state of a pedestrian but may try to make some inferences about it from available data, such as their visual appearance and previous motions. For example, a large commercial fleet of ADR taxis in a city means that the fleet will likely encounter and recognise the same individual pedestrians many times and be able to learn about them as individuals. Recognition could be done through face detection, clothing style, gait (walking style), historical origins, destinations, and routes of their journeys, and their assertiveness in interactions. Predictions could then be about destinations, routes, and assertiveness.

Profiling is a weaker form of predictive modelling that does not attempt to recognise individuals but to classify them into clusters having stereotypical attributes. For example, an ADR might learn that middle-aged males wearing suits at lunchtime are expected to have high values of time and behave more assertively than young females wearing casual clothes. Age, gender, clothing style, clothes, hair and skin colour might show statistical correlations with behaviours in some locations. Some of these features or attributes can be varied by choice – such as colours of clothes and sometimes hair (e.g. punks with green hair might be found to be more assertive than people with other hair colours). Others cannot be easily changed. Some are difficult to classify; for example, one can choose what clothes to buy to some extent, but designer clothes are, by intent, only available to rich people. Some, such as age, disability, gender reassignment, marriage and civil partnership, pregnancy and maternity, race, religion or belief, sex, and sexual orientation,[88] referred to as protected characteristics, are politically charged. The law prohibits discrimination based on these characteristics. Therefore, If an ADR becomes more 'assertive' around middle-aged males in suits because it assumes they have a high value of time, it may unjustifiably treat other demographics differently, leading to inequalities in service.

[88]See sections 4–12 Equality Act 2010.

It is crucial to recognise that complications can emerge even when protected attributes are not directly involved. For instance, clothing style may reflect an individual's socio-economic status, which, although not legally protected, can still introduce bias. If an ADR were to favour individuals wearing designer clothes, it could inadvertently display preferential treatment – such as neglecting to apply an otherwise justified small penalty – based on socio-economic status, raising significant ethical concerns. Thus, the design and operational strategies for ADR systems must take into account the potential for profiling that could result in unfair or biased treatment beyond just the legally protected characteristics.

Equally important is the issue of data protection implications due to the ADR's functioning. During their decision-making processes, ADRs will inevitably collect data, some of which may be personal. The management and protection of this data are paramount. The EU and UK GDPR defines personal data as data relating to an identifiable individual. Personal data must be processed according to principles set out in the law, including data specification, data minimisation, data accuracy, data security, storage limitation, and safeguarding of the data. Arguably, in the case of the ADR, the purposes of collecting data could be specified to include liability allocation and evidence in cases of accidents. Other principles, such as data storage limitation, could be more difficult to comply with. On the one hand, Article 5(1)(e) of the GDPR allows personal data to be kept in a form which permits identification of the data subjects for no longer than is necessary for the purposes for which the personal data is processed. On the other hand, personal data could be needed for liability allocation, evidential purposes and resolving insurance and other legal claims. It may thus need to be stored for later use or sharing with law enforcement, the courts, insurers or even designers or manufacturers of the ADR. The data may also be kept for training the model's algorithms to improve its performance or prevent future accidents, errors, or mistakes. While the law does not specify retention periods for the data, and it is possible to argue that uses of personal data in the circumstances above are necessary, the provision is vague and future uses must always be matched with the purposes of collecting the data.

However, UNECE Regulation 157 on Automated Lane Keeping Systems (the ALKS Regulation) offers additional flexibility and clarity. It requires vehicles to have a system to store data, known as a Data Storage System for Automated Driving, or DSSAD, which has the capacity to store data. Such data can be stored for about six months, after which it will be overwritten. However, the UK government can require that data be stored longer (than the regulation provides) without violating UK data protection principles. The Law Commission also made proposals regarding data storage for AVs, which are relevant here. The Commission proposes the establishment of an NUIC authorisation authority, which should require data to be collected and stored to process insurance claims for AVs involved in collisions for 39 months from the date recorded.[89] The law could be changed to allow earlier deletion if it was too long.[90] However, an ASDE (presumably the NUIC operator) must be able to satisfy regulators with details of how privacy concerns will be addressed, including how data will be recorded, stored, accessed, and protected.[91]

A particularly challenging aspect concerning data usage by ADRs pertains to potential profiling and automated decision-making in the context of interaction control. Generally, there is a stringent prohibition against entirely automated decision-making processes, including profiling that may significantly impact the individuals concerned. Article 22(1) GDPR provides that individuals have the right not to be subjected to decisions based purely on automated processing, which includes profiling, especially when these decisions have legal repercussions or similarly substantial impacts.[92]

To articulate the issue more precisely, the questions that arise are as follows: Is it permissible under the law for an ADR to modify its interaction with a pedestrian based on that individual's historical behaviour? Can an ADR lawfully employ this historical data to anticipate the pedestrian's future actions or to infer the likely behaviours of new individuals based on a combination of observable features and data derived from others who have displayed similar characteristics? Moreover, we must consider whether the utilisation of personal data by an ADR to administer a minor penalty qualifies as an instance of automated decision-making within the context of GDPR. It is crucial for ADR systems to be designed with meticulous regard for legal compliance, particularly in terms of data collection and the automated decisions that may result. This necessitates a thorough legal evaluation and potentially the establishment of processes that allow for human review or intervention, ensuring alignment with GDPR mandates and the protection of individual rights.

It is important first to highlight the subtle differences between profiling and automated decision-making. Profiling is 'any form of automated processing of personal data consisting of the use of personal data to evaluate certain personal aspects relating to a natural person, in particular, to analyse or predict aspects concerning that natural person's performance at work, economic situation, health, personal preferences, interests, reliability, behaviour, location or movements;'[93] According to the Article 29 Working Party (WP29), profiling is a procedure that may involve a series of statistical

[89]Law Commission (n 61), Rec. 73, para 13.52.
[90]Ibid., paras 13.44–13.45.
[91]Ibid., para 5.81.
[92]Exceptions to the rule contained in Article 22(2) are if the solely automated processing is necessary for the performance of a contract, or is authorised by Union or Member State law to which the controller is subject, or is based on the data subject's explicit consent.
[93]Art 4(4) UK GDPR.

deductions used to make predictions about people. It uses data from various sources to infer something about an individual based on the qualities of others who appear statistically similar.[94] The solely automated decision-making is the ability to make decisions by technological means without human involvement. Although it overlaps profiling, automated decisions can be made without profiling.

In the case of the game theoretic ADR control, it is possible to argue that inflicting small penalties on a pedestrian for bad behaviour based purely on the model's algorithmic recommendation is automated decision-making. However, it becomes a decision based on profiling if the model monitors the pedestrian over time. The 'decision' to inflict penalties is based on previous interactions or other characteristics seen in people in the same class as the pedestrian.[95] Clearly, the law prohibits this type of profiling. It would be unlawful for the model to ascribe or predict certain behaviours by a pedestrian based on observations of others with similar characteristics and features. While this prevents clearly undesirable cases, such as treating people with different skin colours differently, it must also prevent other cases which might be viewed as desirable, such as programming an ADR to treat children, older people or disabled people more politely than others.

Regarding automated decisions, however, the further requirement that solely automated decision-making must also affect the data subject's legal rights or significantly affect him or her may not apply. The processing affects legal rights when it impacts a person's rights, such as the freedom to associate with others, vote in an election, or take legal action. It could also affect a person's legal status or their rights under a contract. Processing significantly affects someone if the effects are sufficiently great or important to be worthy of attention, not merely trivial. 'In other words, the decision must have the potential to significantly influence the circumstances, behaviour or choices of the individuals concerned. At its most extreme, the decision may lead to the exclusion or discrimination of individuals.'[96] While the law does not foreclose on the activities that can significantly affect an individual, it is arguable that the model's infliction of small penalties which cause inconvenience or embarrassment may be too trivial to be construed as having a legal effect or similarly significantly affecting a person.

7. Conclusions

The emergence of ADRs in shared public spaces challenges the traditional paradigms of engineering, law and ethics, stretching the boundaries of how

[94]Article 29 Data Protection Working Party, Guidelines on Automated individual decision-making, and Profiling for the purposes of Regulation 2016/679 (Adopted on 3 October 2017) p 7.
[95]The example is derived from the WP29 Guidelines on Automated Decision Making, see p 8.
[96]WP29 Guidelines on Automated Decision-Making p 10.

we perceive and legislate for non-human agents in our midst. In science fiction, Azimov's First Law of Robotics posited an influential fundamental rule – a robot may not harm a human or, through inaction, allow a human to come to harm. However, this fictional law does not address the nuanced dilemma ADRs face in prioritising between minor harm to a pedestrian versus potential harm to a recipient due to delayed delivery, whether the goods are of an urgent medical nature or of more mundane commercial value.

Our exploration into the game-theoretic interaction of ADRs and pedestrians suggests that for ADRs to function effectively and avoid the so-called 'freezing robot problem,' they must be programmed with the capability to administer minimal negative utility penalties to pedestrians under certain circumstances. The application of such penalties is not straightforward; it requires careful legal and ethical considerations, balancing the rights and safety of pedestrians with the need for efficient delivery services.

To legally enable ADRs to perform their functions within this framework, a number of legal changes are necessary. Currently, ADRs operate in something of a grey area, with existing laws not fully addressing their unique operational needs. For ADRs to fully integrate into the societal fabric, they need to be recognised under a new or existing legal classification, which will dictate the rules of their operation and interaction with other road and pavement users. There is a need for explicit laws allowing ADRs on sidewalks and pavements, with clear guidelines on their usage. Moreover, considering the assignment of a form of limited 'personhood' could pave the way for handling complex issues of liability and responsibility.

While some of these changes could potentially be shaped by judicial decisions, such as a judge ruling that ADRs be treated as pedestrians for legal purposes, significant alterations would necessitate legislative action. This includes the establishment of a legal classification for ADRs, adjustment of road laws to permit their operation, assignment of personhood, and the crafting of special permissions for sensitive tasks. Adjustments are also crucial to address the potential for profiling and automated decision-making that could lead to discrimination or privacy violations. Instituting such changes will not be trivial; it will require a concerted effort involving stakeholder consultations, legal reforms, and possibly new laws to ensure that the introduction and operation of ADRs are beneficial, fair, and ethically sound. Only through such a comprehensive approach can we reconcile the innovative potential of ADRs with the timeless values of safety, privacy, and equity in our public spaces.

Data accessibility

This is not an empirical data study, it is based rather on publicly available legal information and argumentation.

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Notes on contributors

Subhajit Basu is Professor of Law and Technology at the School of Law, University of Leeds, Leeds, UK.

Adekemi Omotubora is based in the Faculty of Law at the University of Lagos, Lagos, Nigeria.

Charles Fox is a Senior Lecturer in the School of Computer Science at the University of Lincoln, UK.