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Autonomous vehicle innovation and implications on adoption, liability and policy, using quantum technologies and artificial wisdom

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Autonomous Vehicle Innovation and Implications on Adoption, Liability and Policy, Using Quantum Technologies and Artificial Wisdom

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I hereby declare that this Master's thesis is my original work
and it has been written by me in its entirety.
I have duly acknowledged all the sources of information
which have been used in this thesis.

This Master's thesis has also not been submitted for any degree
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Chia Jie Jun Jeremy
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Autonomous Vehicle Innovation and Implications on Adoption, Liability and Policy, Using Quantum Technologies and Artificial Wisdom

This paper will explore the use of two new innovations for the issues facing autonomous vehicles (AV), those of quantum technologies and artificial wisdom. The issue of delayed at-scale commercialization and adoption of autonomous vehicles due to the extensive dynamic capability required to derive an optimal process solution for any complex, dynamic and adaptive autonomous vehicle ecosystem is shown to be resolved by the use of these innovations, will be shown to be more widely applicable for other issues for AV and for any scenario where automated decision making is required.

QC might open up the door for the application of the Wisdom Approach in the AV industry and technology in a broad manner while enabling the creation of an Ethics Chip by adopting the Wisdom approach. Artificial Wisdom embodies a dynamic capability which will be able to derive an optimal process solution for any complex, dynamic and adaptive system that involves constructs with inherent instability. It will enable AV car makers to create a car that universally fulfils the ethical frameworks adopted by populations around the world, even in the absence of agreement on a global moral code; and the issue of delayed at-scale commercialization and adoption of AVs.

Section 1 presents the background information of the paper. The context of the AV industry and its workings are presented in Section 2, while Section 3 presents details of Quantum Computing. Section 4 introduces the subject of Artificial Wisdom and the Wisdom Approach, the proposed use case and the concept of the Ethics Chip. Finally, a conclusion is presented in Section 5.

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Keywords: Autonomous Vehicles, AV, Driverless Cars, Insurance, Premiums, Liability, Quantum Computing, Machine Learning, Artificial Intelligence, Artificial Wisdom, Wisdom Approach

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1. Introduction

Unexpected delays by Autonomous Vehicles (AV) makers in the AV development timeline provide industry players with an opportunity to study and prepare for the downstream implications of AV adoption. The current process for assigning liability in AV-related accidents is foreseeably problematic, given the voluminous and complex nature of data that both support the vehicles' autonomous functions and aid in liability investigation. The shift of liability from drivers to car-manufacturers also demand that AV product liability claims processes are streamline. To overcome these challenges, we suggest using the Wisdom Approach[1] (developed by Dr. Brian R. Tan) to create Artificial Wisdom in order to support a liability claim framework such as the Single Insurance Policy which was initially introduced by the UK government in 2018 (AEVA 2018). By adopting a framework that uses wisdom elements[2], the policy would see a more structured apportionment and establishment of liability between the relevant parties. This allows insurers to more accurately determine the appropriate amount to compensate the insured or the injured party in a collision caused by AV, irrespective of whether the human or automated technology was responsible for it. This would greatly simplify the product liability discussions and data forensic investigations for the insurer, the vehicle manufacturer/ technology provider and relevant specialists, allowing injured victims to have access to quick and fair compensation. Additionally, legislatures can be introduced such that a data-sharing arrangement between vehicle manufacturers and insurers can be made to aid in liability investigations. The application of the Wisdom Approach here would enable all parties to utilize a common universal language, method and framework,

[1]It should be noted that all aspects of the Wisdom Approach and Artificial Wisdom will be based on work done solely by Dr. Brian R. Tan. Outside knowledge, understanding and definitions of any wisdom-based methods or of artificial wisdom will not be comparable as references or related to what is utilized for this dissertation. The Wisdom Approach is deemed to be a completely novel and currently proprietary creation.

[2]Wisdom elements are identifiable constructs of a fundamental nature identified under the Wisdom Approach.

fingerprinting[3], where the characteristics of the wisdom elements ensures that synchronization considerations across the autonomous vehicle ecosystem is achieved and maintained.

Apart from changing policy, the introduction of AV might see insurers needing to change their current sources of revenue. The adoption of AV would cause steep declines in overall automotive premiums, owing to an expected decrease in accident rates. According to National Highway Traffic Safety Administration's (NHTSA) Fatality Analysis Reporting System, 94% of serious car accidents which are caused by human error could be reduced with the introduction of AVs. However, these losses can be offset with new insurance product lines that center on AV. New AV-related insurance product lines include cyber security, product liability and infrastructural issues.

The entry of new Quantum Computing ("QC") capabilities for commercial purposes such as IBM's Q System One (IBM 2019) is expected to change the playing field across many industries and brings about tangible implications for the automotive industry as well. Whilst QC is inevitable and undoubtedly on its way, large-scale adoption would likely occur five to ten years from now. Employing Quantum Computing technologies and using the Wisdom Approach can potentially reduce data and computing power requirements significantly and reduce the expected time required for large-scale adoption of QC in the AV ecosystem by the creation of less arduous requirements; along with reaping the benefits of potential synergies arising from the combined employment of the Wisdom Approach and Quantum Computing technologies. A valuation by McKinsey (Burkacky, O., Mohr, N., & Pautasso, L., 2020) estimates that the overall market value of QC services to be up to US$52 billion in 2035 with about 10 percent of that will come from

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[3]Elemental fingerprinting is a method utilized by the Wisdom Approach to make objective comparisons between thought constructs, whereby thought constructs are defined as constructs that require thinking and bear characteristics of inherent instability. For the purpose of this dissertation, thought constructs (also known as Wisdom elements) of the most fundamental manner are utilized for elemental fingerprinting.

advanced-industry players' spending, including automotive companies wanting to capture QC's benefits. Broadly speaking, the main application of QC technology to AV adoption in an insurance context would center around QC technology enabling automotive and insurance companies to process large amounts of data and accelerate learning in autonomous vehicle navigation algorithms at an unprecedented rate.

In order to have a much better chance of enjoying long-term success, insurers today have to come to terms with the rapidly changing marketplace that faces them, and through aggressive research, pivot in the right direction moving forward.

2. Autonomous Vehicles (AV)

Introduction: Autonomous Vehicles (AV)

As with putting a man on Mars, it had seemed that for a while now, we were on the cusp of another breakthrough for mankind and technology—driverless cars. While not quite so *out-of-this-world*, the promise of autonomous vehicles (AV), predicated upon AI progression in the mid-2010s, seemed impending and inevitable. Years later, we find ourselves making progressing and yet, still remaining at the brink of a breakthrough. Enthusiasm from the public may have waned through years of failed promise and deliverables. To the technological giants, car manufactures and investors, however, the dream is very much alive and more tangible than ever. Companies such as Waymo, continually attract investors; The autonomous vehicle unit of Google's parent company, Alphabet, reported having received $3 billion from outside investors earlier this year (Reuters, 2020).

Recent AV investments into other similar firms include General Motors' Cruise unit raising a further $1.15 billion in May 2019 (Ohnsman, 2019), Uber raising $1 billion in April 2019 (Bosa, 2019) and Nuro raised $840 million in February 2019 (Reuters, 2019). Apart from privately own companies, the promise of autonomous vehicles has also attracted strong interest from government ministries. In Singapore, a joint team was developed, consisting of the nation's government ministry—the Land Transport Authority—, JTC Corp (a government agency for sustainable industrial development), the traffic police, and the Centre of Excellence for Testing & Research of AV- NTU (CETRAN), a research centre supported by engineers from National Technological University. The Singapore government had also awarded funding for AV trials to organizations such APTIV (Delphi, NuTonomy), Singapore Technologies and NTU-Volvo, following a call for collaboration earlier in 2019 (Razdan, 2020). In 2020, Singapore was ranked first in the world according to the Autonomous Vehicles Readiness Index – a measure of a nations readiness to adopt

AVs through the four domains of: 1) Policy and legislation, 2) Technology and Innovation, 3) Infrastructure, and 4) Consumer acceptance (KPMG, 2020). With such funds and even government support, the question then remains: *Where are our driverless cars?*

How Driverless Cars Work

The driving process in its fundamental form involves two components. First, it involves the observation of the surrounding environment—traffic lights, pedestrians, lane markers, oncoming vehicles, etc. Second, it involves problem solving and decision-making, based on the observed environment, and previously learnt memory (i.e., learnt traffic rules). In autonomous vehicles, the observation component uses a combination of technology such as radar, LiDar and ultrasound, to aid in computer vision. No single technology is able to provide the complete coverage needed. The problem solving and decision-making component in AV involves the use of Artificial Intelligence (AI); AV driving decisions are the aggregated result of observations gathered by computer vision, previously learnt responses and algorithms input by programmers.

While the working model for driverless cars exists, translating this model to a working vehicle has been challenging. The issue here is the complexity of the driving process itself. Driving is a terribly complex process, where following a list of rules of the road is rarely enough. There are many nuanced things that we do when driving, such as making eye contact with others to confirm who has the right of way, adapting to weather conditions, and making split-second judgement calls that are not encoded explicitly in driving rules. To add to the complexity of driving, driving is also a dangerous task. Linguistic nuances missed by the AI in a smartphone may lead to user frustration, but driving nuances missed by AV AI could result in death. On March 18, 2018, a self-driving car had run down Elaine Herzber, a 49-year-old pedestrian, even whilst having a safety driver behind the wheel; Elaine was run down while walking her bicycle across the road (Griggs, & Wakabayashi, 2018). Investigations later revealed that the Uber self-driving test vehicle involved in the accident had failed to recognise her as a pedestrian (BBC News, 2019).

Consequently, enormous training data— both in the form of computer simulation and actual autonomous driving data— is needed for AI deep learning to overcome the task complexity and the low margin for error involved in driving. By having more training data, the AI can better learn how to respond in a variety of situations, consequently making more accurate and safer driving decisions.

This is where the development for AV is currently at— collecting as much driving data as possible. A reason AV development companies have attracted staggering sums of investments, apart from purported benefits, is this current state of AV development, i.e., driving data collection. This late stage of development suggests an "inevitability" to fully-autonomous vehicle; The question is not if, but when (in the sense of the conditions: data – volume, quality, velocity, type, and processing ability) will we get AV. When will the data collected be enough? Every year, with more aggressive data collections measures being taken by industry players, aided by local government bodies, we are evermore closer (Editorial, 2020).

However, it might be wise to note that there are constantly evolving scenarios with different driving conditions and idiosyncrasies across the world (e.g. some people/countries use the horn primarily for polite reasons, others use the horn as a means to vent frustration or for safety reasons) means that the same data in a different context will have a different meaning or that the data can be translated differently, and using the datasets from one locale may not apply well into another locale. The ever-changing environment will also mean that data can and will be outdated eventually; hence data collection might become a need that never gets fulfilled in its entirely.

Adoption Benefits of AV

Despite delays in the AV timeline, companies continue to invest into these projects because when AV happen, it will change a lot for the world. The principal benefit of AV, as with most automated processes, is to remove human error. Local data suggest that around 96.4% of automotive accidents have been related to driver error, 52.9% of which resulting in fatality

(Ministry of Home Affairs- Singapore Police Force, 2019). A similar statistic has been reported in the US, with 94-96% of all automotive accidents found to be due to human error (National Highway Transportation Safety Administration, 2017). By removing human error from the driving process, these statistics are expected to decrease drastically – experts have predicted the frequency of vehicular accidents to drop by 35% to 40% (KPMG, 2015b). An implication of increased safety, the automation of driving would also promote healthy ageing—by providing the elderly with freedom of mobility whilst ensuring road safety, an important consideration in light of recent population trends. According to a recent UN report, the number of older persons worldwide is projected to more than double in the next three decades, reaching more than 1.5 billion persons in 2050 (United Nations, Department of Economic and Social Affairs, Population Division, 2020); in Singapore, the number of adults aged 65 years and older will jump from 12.4% to 33.3%. Having a transport system that is inclusive, accessible and safe for older adults is therefore fundamental. On top of its principal benefits of safety, current literature suggests AV adoption, specifically in a shared autonomous vehicle (SAV) model, could bring other benefits such as reduced travel cost, parking demand, and carbon emissions, while optimize road capacity, and promoting social and transportation equity (Golbabaei et al., 2020; Greenblatt, & Shaheen, 2015; Land Transport Authority, 2017; Taiebat et al., 2018).

With evidence of technological feasibility as well as purported benefits, it is clear that driverless cars are the way forward. What is unclear, however, are the downstream implications of AV adoption. This research commentary aims to discuss the downstream implications of AV adoption with respect to Liability and Policy, Declining Premiums and Emerging Opportunities

Liability Considerations

In Singapore, as with many other countries, automotive insurance is compulsory. A key reason for this is to protect all road users and to make sure that following an accident, all parties involved are covered. Car accidents are costly and tend to involve other third parties. A driver colliding with a bus may incur medical costs not just for himself, but for the passengers on the bus. Property damages may not be confined to just the car and bus involved, infrastructural damages to nearby structures, such as a traffic light, may also result. These third party liabilities can be very costly, and having mandated automotive insurance will protect road users involved in accidents on both ends. The current model of automotive insurance and its premiums has been well-established. An underlying assumption behind automotive insurance is that human error causes accidents. Automotive insurance premiums are dictated by personal factors such as age, years of driving experience, and accident history. Premiums are charged accordingly, with variances in each of these risk factors individually contributing to the overall set premium of the insurance policy. Younger, more inexperienced drivers, and drivers who have gotten into accidents more often, tend to get into accidents more often. Premiums for these groups of individuals are hence, charged at a higher rate. In return for paid premiums, insurers cover property damages (e.g. vehicular theft and damage), liability (legal responsibility from accident), and medical costs (cost of treatment for sustained injuries).

Widely understood and accepted, this insurance model appears to become obsolete in a world of driverless vehicles. Where there are no drivers committing human errors, who is liable for accidents when they do happen?

Liability and Levels of Autonomy

In addressing questions pertaining to liability, it is necessary to first distinguish between the levels of vehicle autonomy. Vehicle autonomy discussed in pop-culture paints a picture of fully autonomous vehicles, free of human input and functioning entirely on AI capabilities. While that may be the endpoint, at least in the near future, vehicle autonomy will be introduced in progressive levels. In fact, evidence of partial vehicle autonomy can already be seen in today’s modern cars, through functions such as cruise control functions, and highway assist systems. The Society of Automotive Engineers (SAE) defines 6 levels of autonomy which categorises the extent to which the Autonomous Technology (AT) is capable of supporting and assisting the driving tasks, starting at level 0, they are: 0) No automation, 1) Driver assistance, 2) Partial Automation, 3) Conditional Automation, 4) High automation and 5) full automation (SAE On-Road Automated Vehicle Standards Committee, 2014; see Table 1).

Table 1: Levels of Vehicle Autonomy

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
Human driver **monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
Automated driving system **("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Note. Reproduced AS-IS with permission from SAE-International J3016^{TM}. SAE On-Road Automated Vehicle Standards Committee. (2014). Taxonomy and definitions for terms related to on-road motor vehicle automated driving systems. *SAE Standard J, 3016*, 1-16.

Through these distinctions in levels of vehicular autonomy, it is perhaps unsurprising that liability varies accordingly. At level 0, the human driver is involved in all aspects of the driving process; He/She is liable when his/her vehicle is found to be culpable in an accident. At level 1 and 2, while the vehicle may provide some form of assistance, the current litigation system presumes the driver to be in control of the vehicle at all times. In a 2016 investigation by the

National Highway Traffic Safety Administration (NHTSA) in the US on an accident, the federal agency pointed out the even if Advanced Driver-Assistance Systems (ADAS) were present (i.e. SAE level 2 Autopilot systems), driver's continuous supervision is warranted (Habib, 2017). Similarly, while Tesla's "Autopilot" system implies the car's ability to drive itself, its user manual reminds drivers to be continuously ready to intervene (Pinter et al., 2017). These examples demonstrate the clear emphasis of responsibility being placed on drivers for SAE levels 1 and 2. Nonetheless, should the driver feel that there is evidence to support the fact that equipment failure was responsible—in part or as a whole—for the accident, the driver can claim product liability from the car manufacturer. The process of product liability claim however, in its current state, is arduous and potentially prohibitively expensive . Following a liability claim, investigations have to be conducted to determine if the fault of the accident lies with the human driver, the vehicle's software and/or hardware, perhaps even a combination of the two. These investigations can prove to be challenging, as the same technology that enables the vehicle's autonomous functions— a voluminous amount of proprietary code and data—may also abstruse the transparency of the vehicle's technological errors and decision-making processes (Singapore Academy of Law, Law Reform Committee, 2020). Given this obscurity, proving the liability of the car by gathering evidence and evaluating it becomes difficult, requiring the support of technology forensics specialist and for car manufacturers to cooperate in investigations by releasing crucial vehicle data.

When SAE levels 3 to 5 vehicles become more common place, it stands to reason that issues of liability attribution may be even more problematic, due to more frequent product liability claims against these highly autonomous vehicles following accidents. At SAE levels 3 to 5, the vehicle's primary functions rely more on AI technology and less on human input, as compared to SAE level 1 and 2. While lesser accidents are expected to happen, a larger proportion of accident liability claims may shift from driver negligence to product liability given the larger role AI software and hardware play in the driving process. A greater amount of proprietary code and data is most likely needed to support these highly autonomous vehicular functions, and greater support from technology forensics specialists and car manufacture will be required when investigating a product liability claim. With the current paucity of privately-owned SAE level 3 to 5 vehicles on the road, it is unclear as to if the law will maintain the emphasis of responsibility being on drivers . Regardless, product liability claims against these autonomous vehicles will still prove to be arduously prohibitive unless legislature reforms are introduced to make liability claims against AV as hassle-free as with negligence in common law jurisdictions. As illustrated, even in countries where automotive insurance is made mandatory with the intent to protect road users, compensation in the case of AV-related accidents is, as of now, not guaranteed.

A Single Insurance Policy

In 2017, the UK government raised similar concerns over this liability claims conundrum. Due to the existing liability claims model, victims of collision involving an AV were disadvantaged in securing compensation in a timely manner (Centre for Connected and Autonomous Vehicles, 2017). They might potentially have to wait much longer than the estimated average claim duration of between 4 to 9 months for non-AV-related accidents (Willis, H., n.d.).

As there had been no established claims procedure for AV-related accidents, these victims would have to take the vehicle manufactures through costly and time-consuming court processes. Additionally, victims of these accidents may not have been covered for collisions as a result of AV hardware and/or software failure. The UK government passed into law the Automated and Electric Vehicles Act 2018 (AEVA 2018), aimed at addressing these issues. AEVA 2018 was fashioned to ensure that victims of AV accidents, from SAE levels 1 until 5, had access to fair and quick compensation. The AEVA 2018 states that AVs require insurance under a single insurance policy, that covers both the driver and the vehicle. The single policy requires that insurers compensate the insured injured in a collision caused by AV, irrespective of if the human or automated technology was responsible. If the accident was later found to be the result of the vehicle's automated technology, after compensating the injured people, the insurer can recover any liability payments from the party responsible for the collision, such as the vehicle manufacturer or the technology provider. However, if the AV accident was found to be caused by the owner/operator's negligence (e.g. failing to update AV software), the single insurance policy would only pay up to the minimum legislated amount for the accident. To aid in this process of liability investigation, a data-sharing arrangement between vehicle manufacturers and insurers could also be made (Insurance Bureau of Canada, 2018); This agreement would allow vehicle owners and insurers access to prescribed data, such as data regarding if the vehicle was in automated or manual mode, to help determine the cause of the accident. The notion of AV manufactures being transparent with data is not novel. According to California Code of Regulations (CCR) on AV on public roads, article 3.8 specifies that AV needed to be equipped with data recording technology that "captures and stores autonomous technology sensor data for all vehicle functions controlled by the autonomous technology at least 30 seconds before a collision with another vehicle, person, or other object while the vehicle is operating in autonomous mode" (13 CCR § 228.06). The CCR also specifies that data captured and stored by the data recorder must be in a read only format that is capable of being accessed and retrieved by commercially available tools.

The intent of the single insurance policy is to allow injured victims to have access to quick and fair compensation, while leaving the product liability discussions to the insurer and the vehicle manufacturer or the technology provider. Insurers in the UK were found to be in support of the approach taken in the AEVA (Brown, 2018). This expectation seemingly stemming from the notion that it is against AV manufacturer's commercial interest to resist cooperating with insurers; Should insurers be consistently denied the opportunity to recover their costs, insurers could choose to not provide insurance coverage for AV altogether (Centre for Connected and Autonomous Vehicles, 2016). To further assist insurers in liability payment recovery, the Insurance Bureau of Canada (IBC, 2018) suggests for the deductible to apply to not just to individual claims, but a given event. This would allow insurers to recover liability payments—apart from individual claims valued higher than the deductible—but also from the aggregated cost of claims that exceed the deductible, even if each individual claim falls below. An example for this would be in a case of system failure resulting in multiple collisions between AV vehicles, with each individual claim falling below the deductible.

Through this discourse, it appears that the margin of error for AV car manufacturers is ever so slim. With one road to success and many leading to failure, one might consider how AV manufacturers will remain economic. A single software issue or breach in the network of these AVs can result in widespread accidents wherever these vehicles roam . Apart from a significantly heftier responsibility being placed on AV manufacturers, the popularity of car-sharing options has led automotive executives to believe that a drop in car ownership is to be well expected. According to a KPMG's Global Automotive Executive Survey (2017), 74% of UK automotive executives believe that private car ownership will be reduced by half by 2025, with a shift towards mobility-as-a-service. A reduction in product sales and the potential to make huge financial losses through product liability pay-outs, the traditional automotive business model that centers around vehicle ownership may not be viable. Despite these, the future of AV is still very much bright; it will just rely on a radically different business model from what the automotive industry has been used to. According to Dieter Becker, KPMG's Global Chair of Automotive, auto companies will have to develop new service- and data-driven business models together in one digital ecosystem, with its end users at the center (KPMG, 2017). The traditional model of pure product profitability is soon to be obsolete. Carmakers' economics will not only rest on the quantity of vehicles sold, but on the customer value over the whole lifecycle in this new digital ecosystem. With this new service- and data-driven model, new risk such as threats to data security, software and network failure will be seen within the auto industry, providing new opportunities for insurers and underwriting services .

Premiums Decline and Emerging Opportunities

Traditionally, automotive insurance premiums have been dictated by personal factors such as age, years of driving experience, and accident history. With the adoption of AV and the shift of liability from drivers to car-manufactures, a new model for pricing accident premiums will be needed.

One of the major purported benefits of AV is its capacity for safety—removing human error from the driving process . The partial automation of vehicles through Advanced Driver Assistance Systems (ADAS) such as automatic emergency braking, lane departure warning systems, collision avoidance systems, etc. (see Lindgren & Chen, 2005), having already shown to reduce accidents significantly (Cicchino, 2018; Insurance Institute for Highway Safety, Highway Loss Data Institute, 2019). As such, experts have predicted the frequency of vehicular accidents to drop by 35% to 40% (KPMG, 2015b). While the costly nature of advanced safety technology may increase premiums in some regard, with predicted repair cost for AV to increase by 25% to 30% (KPMG, 2015b), a persistent decline in accident frequencies would still initiate a drop in industry loss costs overall. Premium trails loss costs. The auto insurance is an established and competitive industry. Insurers would likely drop prices in order to stay competitive, reflecting consumer demand for lower premiums for fewer accidents. Overall pure motor premiums are expected to reduce by 20% in 2025, and by 40% at the time of hypothesized complete AV adoption in 2050 (Aon Benfield, 2016). As the size of the market shrinks, frantic competition can be expected with firms attempting to maintain premium volume to cover operational expenses and/or market share (KPMG, 2015a). Insurers could potentially lose sight of pricing business for profit; Irrational pricing behavior by either well-capitalized or troubled companies could cause a dangerous downward underwriting spiral for the broader industry (KPMG, 2015a).

The auto insurance industry will be faced with significant challenges in the years ahead. The transition from traditional vehicles to AV has some experts predicting a 40% decline in pure motor premiums by 2050 (Aon Benfield, 2016); Others have valued this to result in an annual loss of around $35 billion dollars in revenue, occurring in the same year (Accenture & Stevens Institute of Technology, 2017). However, with every challenge, comes opportunity. Models designed by Accenture and Stevens Institute of Technology (2017) have suggested that the revenue decreases caused by AV can be significantly offset with new insurance product lines that center upon these very same vehicles; these new insurance product lines are namely: 1) Cyber security, 2) Product liability insurance and 3) Insurance against infrastructure problems.

Cybersecurity

The primary goal of AV is to reduce the role of human error in the driving process and resultant accidents and fatalities. Yet, it is once again humans that pose the greatest threat to these vehicles. AVs are currently being developed and sold with increasing levels of connectivity and automation, and as with all networked computing devices, increased connectivity often results in a heightened risk of a cyber security attack (Parkinson et al., 2017). Unlike traditional vehicles, AVs provide insurers opportunities to protect against cybercrime, such as tampering of vehicle's sensors, modify codes on software, infiltrating hardware, implanting malware (Evas, 2018; Petit et al., 2014) leading to, for example, locking people out of their cars, causing crashes, etc. As these vehicles also tend to contain a host of data—ranging from sensor perception data of the environment collected through cameras, to personal data, insurers may also wish to offer protection against the privacy and misuse of such data.

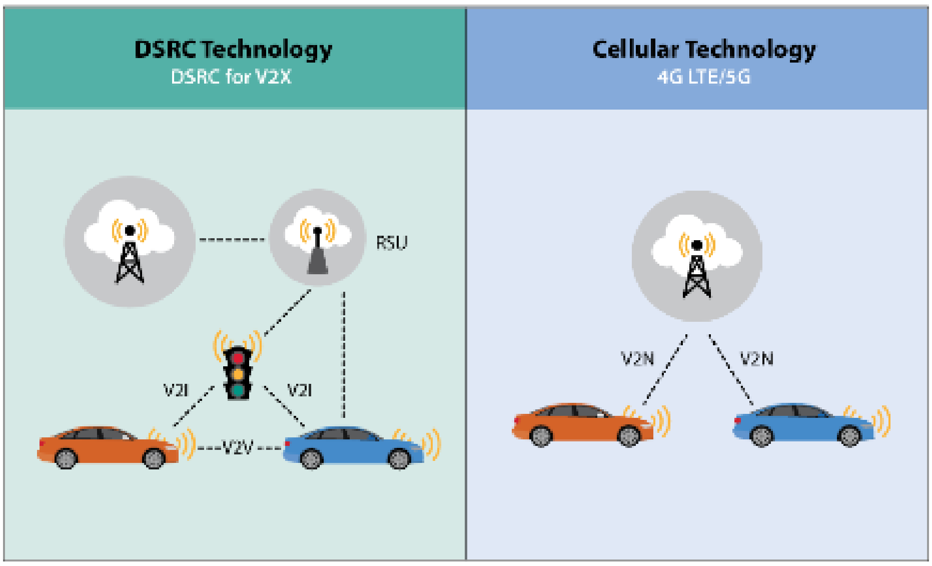
Product Liability

The shift in liability from drivers to manufacturers provide insurers the opportunity to write policies to cover manufacturer's liability. Product liability doctrines may apply to AV in 3 regards: Manufacturing Defects, Design Defects, and Failure to Warn (Gurney, 2013). Manufacturing defects would constitute an autonomous equipment failing to function as specified by the manufacturer; For example, sensors not detecting oncoming traffic as required by the specifications. Design defects, according to the Restatement (Third) of Torts: Products Liability, Section 2(b) (1998), constitutes a product design— in this case, AV design— that would impose a foreseeable risk of harm to the user, a risk which could have been reduced or avoided by the adoption of a reasonable alternative design by the manufacturer, and having omitted the alternative design renders the product not reasonably safe. Lastly, in accordance to the Restatement (Third) of Torts: Products Liability, Section 2(c) (1998), AV manufactures failing to inform buyers of foreseeable risks of harm posed by the product, and/or failure to inform buyers on how to use the product safely, rendering the product reasonably unsafe, would constitute as a failure to warn. Besides liability coverage for original equipment manufacturers (OEMs), insurers can also provide coverage for tier 1 and tier 2 suppliers (Accenture & Stevens Institute of Technology, 2017).

Infrastructure

Autonomous vehicles, whose AI and technology are generally self-contained, are largely designed to be part of a larger category of connected vehicles and infrastructure (Canis, 2020). AV technology, especially among vehicles closer to full-autonomy, would increasingly depend on external infrastructures to support its function through an exchange on information, or V2I (vehicle-to-infrastructure) interaction. Communications with various infrastructures, other vehicles (vehicle-to-vehicle, V2V) and networks (vehicle-to-network, V2N) will need to occur continuously so as to capture and interpret complete data concerning the surrounding environment, allowing the AV to make driving decisions based off this data— such as whether to accelerate, break or steer (see Figure 1). AV OEM may choose to leverage on existing external infrastructures, such as existing cloud-based services like google. Infrastructures such as Road Side Units (RSU)—which are units along roads that communicate and provide AV with information—may also be separately managed by infrastructure operators. These AV infrastructures and their various stakeholders will require their own insurance policies, providing opportunities for insurers.

Figure 1: Vehicle Communications Systems



Note. Acronyms used in this image are DSRC, representing dedicated short-range communication, V2X (vehicle-to-everything), representing a combination of V2V and V2I. V2N is illustrated by the connecting of vehicles to cellular infrastructure and cloud systems. Drivers can take advantage of services such as traffic and software updates, communication between vehicles, and storing the large amount of data it processes onto cloud-based systems. In addition, other infrastructure such as RSUs allow communication from vehicles and infrastructure to cell towers, signaling and coordinating traffic. Reproduced with permission from Congressional Research Service (CRS). Canis, B. (2020). *Issues in autonomous vehicle testing and deployment* (R45985). Congressional Research Service. https://fas.org/sgp/crs/misc/R45985.pdf

The cumulative value of these new sources of revenues is tremendous, amounting to an estimated $81 billion by 2025; Due to potential gains being realized prior to premium declines, accumulated premiums losses are not expected to exceed revenue from these new sources of gain until 2050 (Accenture & Stevens Institute of Technology, 2017). Insurers whose revenues primarily rests on personal automotive policies should look to transition into commercial insurers, writing policies for a small number of large risks. As millions of personal auto insurers may soon be replaced with a smaller number of commercial carriers, industry players ahead to these changes—with regards to policy development, administration and distribution— will have a greater surviving chance (Accenture & Stevens Institute of Technology, 2017).

Summary on Autonomous Vehicles

Unexpected delays in the AV development timeline provide industry players with an opportunity to study and prepare for the downstream implications of AV adoption. The current process for assigning liability in AV-related accidents is foreseeably problematic, given the voluminous and complex nature of data that both support the vehicles' autonomous functions and aid in liability investigation. The shift of liability from drivers to car-manufacturers also demand that AV product liability claims processes are streamline. We suggest an adoption of a Single Insurance Policy, initially introduced in 2018 as the Automated and Electric Vehicles Act (AEVA 2018) by the UK government. This single policy aims to leave the product liability discussions and data forensic investigations to the insurer, the vehicle manufacturer/the technology provider and relevant specialist, allowing injured victims to have access to quick and fair compensation. Additionally, legislatures can be introduced such that a data-sharing arrangement between vehicle manufacturers and insurers can be made to aid in liability investigations. Apart from changing policy, the introduction of AV might see insurers needing to change their current sources of revenue. The adoption of AV would cause steep declines in overall automotive premiums, owing to fewer accidents. These losses can, however, be significantly offset with new insurance product lines that center upon these very same vehicles. It is clear that many industries are heading into unchartered waters with AV, the insurance industry included. In order to have a much better chance of enjoying long-term success, insurers today have to fight to remain at the front foot, collaborating with AV manufacturers and gathering relevant data whenever possible. Insurers have to come to terms with the rapidly changing marketplace that faces them, and through aggressive research, pivot in the right direction moving forward.

One of the possible disadvantages and some of the constraints arising out of the Automated and Electric Vehicles Act 2018 (AEVA 2018) single insurance policy stems from the need to balance between i) connecting legislature to the technology and ii) giving sufficient space and flexibility for technological innovation and development. 'The more the law seeks to be accurate and comprehensive, the sooner it is likely to be separated from quickly evolving technology that are its regulatory targets,' (Brownsword, R., & Somsen, H., 2009). This is the so-called 'vertical approach to regulatory disconnection,' in which technology neutral words and broader regulatory drafting are expected to have the flexibility to accommodate technology as it develops (Butenko, A., 2016). Broader terms will provide judges more latitude in determining disputes while also allowing producers to build products with more freedom but may result in more uncertainty in its interpretation, becoming less 'calculable and consistent’ (ABI and Thatcham Research, 2019). However, introducing regulation with restrictive terms, and thus less flexibility, may result in the law becoming divorced from the technology since the regulation's covering descriptions might no longer correspond to the technology or the numerous technology-related practices; thus, rendering the regulation to be of limited value as the technology and its application grow further. This would then require periodic review and updating of the regulations (Brownsword, R., 2009). 'Technological neutrality can be regarded as a duty incumbent upon the government or regulatory authority to try to establish laws and regulations that are sustainable over time, rather than requiring review,' (Butenko, A., & Larouche, P., 2015).

3. Quantum Computing

Introduction: Quantum Computing (QC)

In the face of above limitations and uncertainty, how can we then move the technology and insurance forward for insuring AV? Quantum computing ("QC") is hard to miss with its tangible implications for the automotive industry (Burkacky et al., 2020). Much of the attention drawn relates to scientific developments presented by exciting industrial use cases such as those in the automotive and transportation sectors. In 2019, IBM unveiled their Q System One which boasts "the world's first integrated universal approximate quantum computing system designed for scientific and commercial use" (IBM, 2019). In another leap, D-Wave Technologies announced in 2020 their 5640 qubit Advantage machine; much more than doubled its earlier record of 2000-qubit.

So what exactly is different about quantum-computing applications? Rather than traditional binary bits as units for information-processing, QC uses quantum bits, also known as "qubits". Qubits can be physically generated through various methods, often requiring control over electron spin. Scientists find a property in materials where they are able to access and control quantum properties, thereby utilising light or electromagnetic fields to create superposition, entanglement, amongst other properties (U.S. Department of Energy Office of Science, 2020), for instance, trapping supercooled calcium ions in a magnetic field and creating interlinked superconducting capacitor circuits.

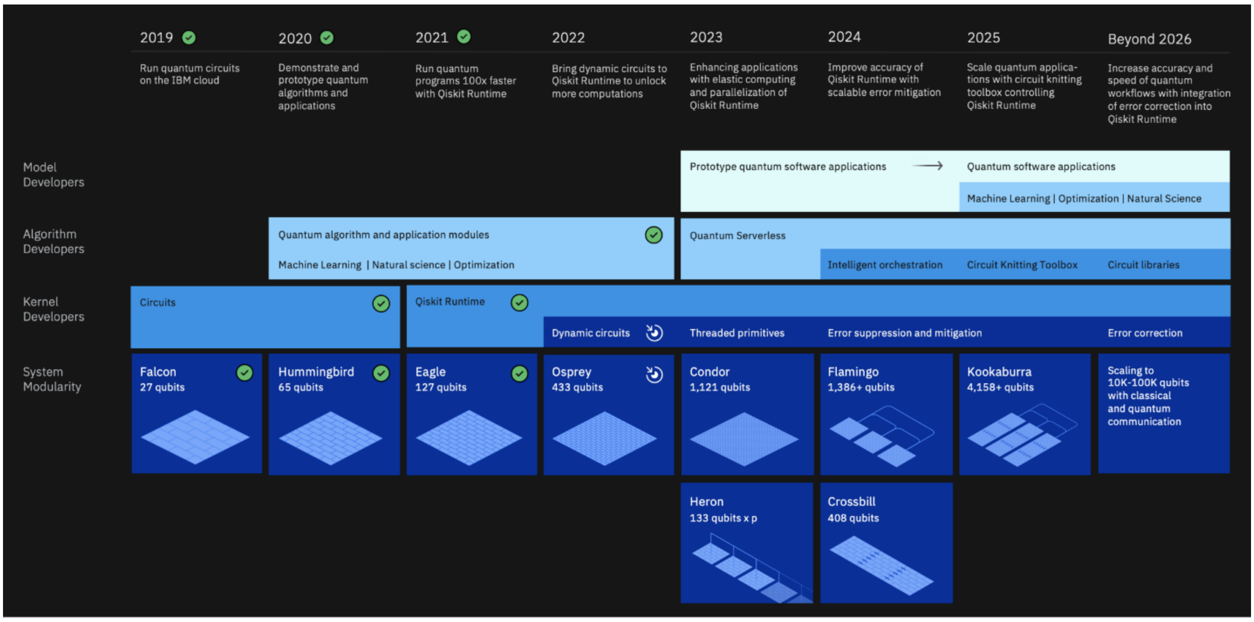
On a quantum level, QC's properties are astounding on multiple layers and many expect it could "change the game in such fields as cryptography and chemistry (and thus material science, agriculture and pharmaceuticals) not to mention artificial intelligence and machine learning . . . logistics, manufacturing, finance and energy" (Gerbert, P., & Ruess, F., 2018). For example, qubit superposition is a probability of being in a 1 or 0 state, qubits also exhibit interference, similar to sound waves cancelling out noise in earpieces, and quantum entanglement where particles remain connected such that an action on one will immediately affect the other, even at large distances. QC's potential is further reflected by Shor's algorithm (Gamble, S., 2019) proving how much it could improve processing time for factoring prime numbers with quantum computers being exponentially faster than the best conventional factoring algorithm the world currently has.

QC has not gone unnoticed, with a report by McKinsey (Burkacky, O., Mohr, N., & Pautasso, L., 2020) suggesting that the automotive and transportation sectors are keen to capitalise on QC's potential, and have even been successful in showing its effectiveness in boosting capabilities across the entire value chain. Several Original Equipment Manufacturers ("OEMs") and tier-one suppliers have begun looking into QC's benefit and its ability to resolve existing problems, especially those relating to route and fuel-cell optimization, and material durability where they have now reached the stage of showcasing its first pilot use-cases. For instance, during the 2019 Web Summit in Lisbon, Portugal, Volkswagen partnered with D-wave to demonstrate a traffic-management system meant to optimise nine public bus routes with the use of predictive analysis (Volkswagen Newsroom, 2019). On the other hand, Bosch, a tier-one supplier acquired a stake in Zapata Computing, a Harvard University start-up, contributing to the US$21-million investment in its Series A (Green Car Congress, 2019).

A Development Timeline for Quantum Computing Technology

Whilst QC is inevitable and undoubtedly on its way, large-scale adoption would likely occur five to ten years from now due to the noise and limited stability of current qubit technology. Thence, industry players contextualise realistic milestones for QC in four stages (Burkacky, O., Mohr, N., & Pautasso, L., 2020).

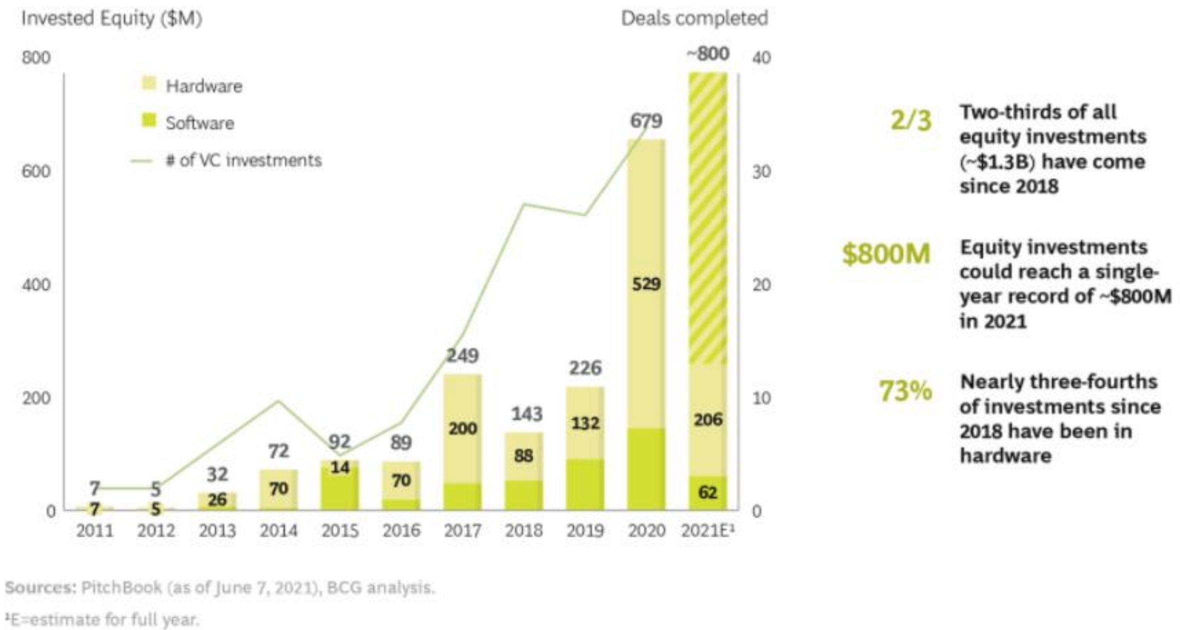
Figure 2: IBM 2022 Quantum Computing Development Roadmap



Source: IBM, 2022

In 2019, Google claimed to have reached the first stage – *demonstration of quantum supremacy* where quantum technology showed a large leap by creating "the first quantum computer that could perform a calculation that is impossible for a standard computer" (Cowan, D., & Diari, T., 2020). In 2020, the record-highest year of equity investments in QC, nearly tripled and it is only set to rise further in 2021 (see Figure 2). And in 2021, IonQ merged with dMY Technology Group III and became the "first publicly traded pure-play quantum computing company", at an estimated initial valuation of $2 billion (IonQ, 2021). Amongst other factors, QC's technical achievement accounts for its rising interest, referencing two highly publicised demonstrations of "quantum supremacy" - one by Google in October 2019 (Murgia, M., & Waters, R., 2019) and another by a group at the University of Science and Technology of China in December 2020 (Bobier,, J. F., Langione, M., Tao, E., & Gourévitch, A., 2021). Both of these solve very specific but not very useful problems. They are also not easily modified for other problems and are currently not accepted by everyone – there have been rebuttals of the supremacy claims by IBM and others (Koetsier, J., 2019). Google claims that its machine Sycamore could make a "calculation that would have taken 10,000 years on even the best state-of-the-art supercomputer took just 200 seconds" (Koetsier, J., 2019). However, IBM rebutted, claiming that Google had calculated incorrectly that traditional computers' RAM storage requirements would be too large to run quickly and had failed to account for the fact that traditional systems can access tremendous quantities of both RAM and hard disk space. Should that have been taken into consideration, that 10,000 years estimate drops to only 2.5days. Xanadu Borealis claims that this would mean that what Google has achieved could at most be considered a quantum advantage, or "quantum utility" (which is used to quantum computers advantageously helping in processing), rather than quantum supremacy.

Figure 2: More than Two-Thirds of Equity Investments in QC Have Been Made Since 2018



Source: BCG Analysis (Bobier,, J. F., Langione, M., Tao, E., & Gourévitch, A., 2021)

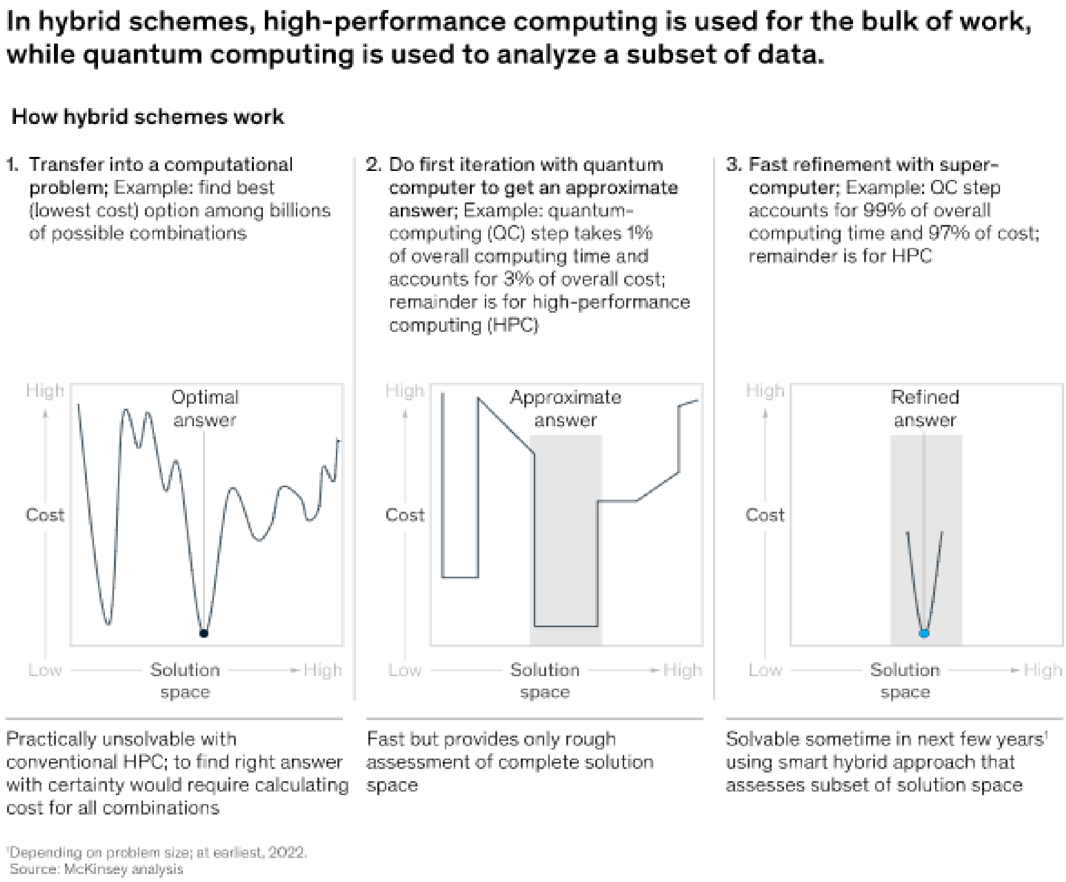
The second stage is the *demonstration of quantum advantage* (also known as quantum utility), requiring practical use-cases which stimulate quantum phenomena, with the first-of-its-kind pilots such as Volkswagen's traffic optimization gradually emerging today. However, complex problem solving, requiring multiple qubits programming would likely only become feasible in 2035 or later.

The third stage, predicted to occur around 2030 (Burkacky et al., 2020), is a milestone where QC "goes public" becoming commercially viable for investment and by which has a*ttained broad quantum advantage* (Burkacky et al., 2020). This would mark the evolution of computing where quantum-computer software will be programmed for tackling specific problems, and where its capability and application will proliferate.

The fourth and final stage refers to the creation of the complete quantum Turing machine, likely viable in the next ten to twenty years. The Turing machine will mean the construction of a full, fault-tolerant universal quantum computer with quantum and random-access memory (Liesbeth, D. M., 2021) and would ideally run on as many qubits as required and perform any algorithm. As well as the hardware, another challenge is the time to convert classical data into quantum data (also called data embedding). This could remove any quantum advantage if the gain from quantum processing is less than the loss from data loading as the data volume scales up. Of course, the loading problem is not an issue for processing natively quantum data such as photons or electrons.

However, in the long-term, QC is not expected to replace all existing high-performance computing ("HPC") due to the nature of various computing tasks where quantum computing may only be suitable and superior for a mere 10 percent of the world's computing tasks (Stewart, D, 2018). QC will always be adopted in a hybrid approach as we live in a classical world and so at least need to see the results as classical bits. Therefore, QC could replace HPC for some processing tasks, but developments are not likely to rely on QC at-scale to solve problems if they are targeted at value creation. There have been successful use-cases that adopted a hybrid format where a QC-based subroutine churns a rough answer for an optimization problem, and the conventional HPC refines this answer with a narrower set of variables (although there are also use cases that do not require a hybrid format with HPCs). Ultimately, leveraging the mature HPCs will enable the gradual employment of infant QCs, allowing programmers to enjoy higher speed and efficiency whilst exploring the technology and its boundaries over the next decade (see Figure 3).

Figure 3: How Hybrid Schemes Work for Quantum Computing with HPC



Source: McKinsey Analysis (Burkacky, O., Mohr, N., & Pautasso, L., 2020)

Assessing the QC Market

A valuation by McKinsey (Burkacky, O., Mohr, N., & Pautasso, L., 2020) estimates the overall market value of QC services to be up to US$52 billion in 2035. It writes that about 10 percent of that will come from advanced-industry players' spending, including automotive companies, that desire to capture QC's benefits.

As the market for quantum technology is developing, it is still unclear which companies (roughly a hundred companies in the space to-date) will come out on top at each segment of the QC value chain (Cowan, D., & Diari, T., 2020). Some of these companies build QC hardware, including D-Wave, IBM, Microsoft, and Rigetti Computing. Others, making up approximately 80 percent, comprise of start-ups with an aim to bridge the value chain gap between hardware manufacturers and end users. They work to translate conventional problems into a quantum logic and build hybrid architectures which allow the combination of classical computers (including HPC) with QC. As such, many stakeholders will ultimately influence and shape the QC market, including hardware and software players and their enablers, even QC-software users are also expected to impact the industry's progress and evolution.

3.1 Hardware

The hardware development space consists of a third of QC companies, with global technology giants and start-ups in the mix and mainly based in the United States (Burkacky et al., 2020). It is a highly competitive market with unclear outcomes as industry players grapple and explore how best to configure hardware and support these quantum computers.

Over the next 15 years, it is anticipated that competing approaches will evolve with QC advancements, and the final methodology will only be revealed with time (Burkacky, O., Mohr, N., & Pautasso, L., 2020). However, it is clear that many hardware companies strive to deliver QC as a cloud-based service, making it unlikely that users will have to set up their own hardware, albeit having the option to. Therefore, companies will have to clarify their goals and decide how they want to access QC services in the short and long term, since on-demand cloud capacity presents as the least expensive and most flexible option in the short run.

3.2 Software

For software development in the QC value chain, the saturation of companies is even higher at about half with start-ups making up the bulk and involving large hardware players, like IBM and D-Wave. This is contrasted to the Hardware space and most are based in Europe and North America. Some of the programs developed for automotive use cases, such as process-design and hardware-design optimization, are expected to be used at scale within the next five to ten years. Whereas other small players also develop process optimization solutions, for instance the German start-up Avanetix, and others aim to optimize the supply chain.

PennyLane is an example of software development in this field, which combines machine learning libraries with quantum simulators and hardware to allow users to train quantum circuits. The conventional scientific computing or machine learning libraries, such as SciPy in Python, are used to perform traditional computations, such as model optimization or training. PennyLane acts as a bridge between classical and quantum computing by providing an interface to these libraries and integrating them with quantum simulators. It enables its users to control and manipulate parametrized quantum circuits or variational circuits on quantum devices, as well as input these circuits into quantum neural networks.

1. The development of such software fuels and enables research advancement in the promising field of Quantum Machine Learning (QML); which arose from the synergy of concepts between Quantum Computing and Classical Machine Learning. For example, in the paper “Binary classifiers for noisy datasets: a comparative study of existing quantum machine learning frameworks and some new approaches”, the authors Schetakis, Aghamalyan, Boguslavsky, and Griffin used PennyLane, the open-source software framework for differentiable programming of quantum computers, to build models that could improve binary classification models for noisy datasets, which are common in financial datasets, using Quantum Machine Learning (QML) frameworks. The authors

were able to show that the proposed classifiers have the potential to improve credit-scoring accuracy Credit rating which will give lenders and counterparties a clearer picture of the credit risk they are facing when doing business. Although there are public credit ratings for large corporations, rating agencies do not provide their services to small and medium-sized enterprises (SMEs). SMEs thus find themselves having a limited access to credit due to the inability to provide transparency due to public credit ratings. Tradeteq provided these datasets, as well as the best classical neural networks (Tradeteq is a value-added service provider to Singapore's Networked Trading Platform (NTP)). The authors, through the use of the open-source software framework PennyLane, was able to show that their novel FH architecture outperforms a number of previously known quantum classifiers as well as some of their best-known classical analogues (Schetakis, N., Aghamalyan, D., Boguslavsky, M., & Griffin, P., 2021; Schetakis, N., et al., 2022).

There are also some start-ups that are looking at automating the conversion of current programs in classical languages that can be compiled and run on conventional or quantum computers, without requiring the users of these programs to have any knowledge in quantum computing – an example for this is Horizon Quantum Computing (Horizontal Quantum Computing, 2020; SGInnovate, 2022). Other start-ups are also looking for a software platform such as Classiq that transforms high-level functional models into optimized quantum circuits.

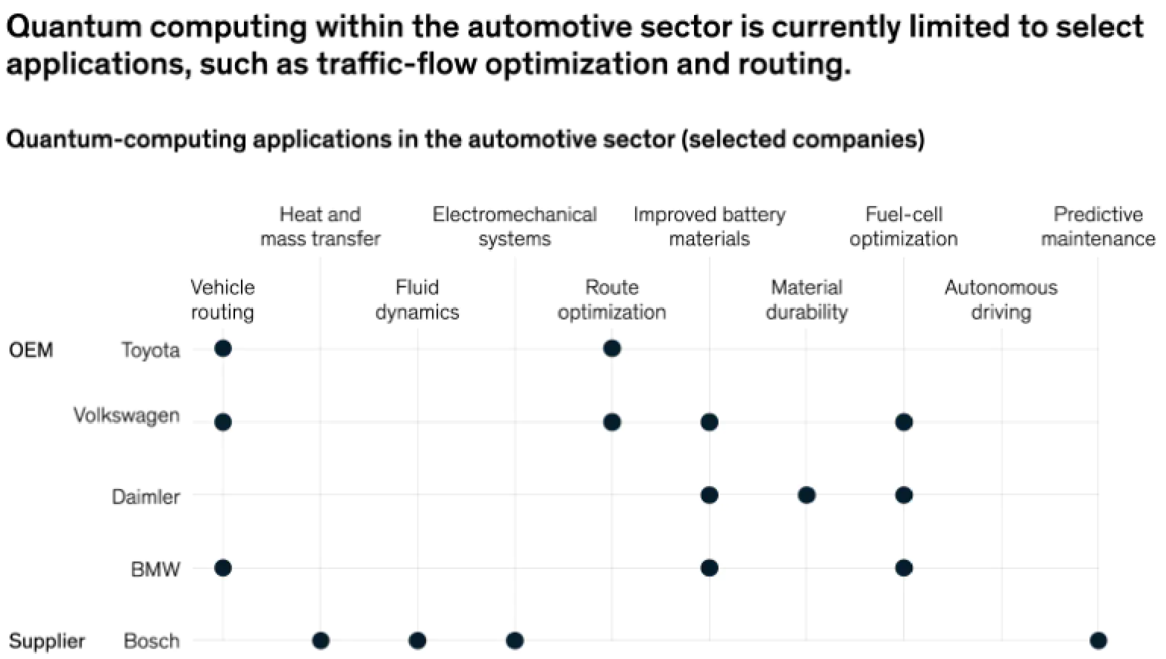
3.3 Enablers

One-fifth of companies serve to enable the provision of solutions. Offerings include existing components, such as cooling units, processing tools for making qubits, and the materials that compose qubits. The specialization could become a potential playing field for some upstream automotive suppliers, including tier-two and tier-three vendors, which produce control units and thermal solutions due to the potential of direct knowledge transfer to quantum computers. And while automotive suppliers may not immediately profit from large-scale-production opportunities while QC is at its infancy, they are expected to in the long term. Furthermore, as the QC industry matures and gains scale and traction, and where a single hardware approach begins to emerge, enablers are expected to become more relevant and benefit.

3.4 QC software users

Many automotive players, including industry leaders like BMW, Daimler, and Volkswagen, have publicly announced their active participation and research into QC, and sometimes partnering with companies in the upstream QC value chain. Similarly, their investigation surrounds the quantum simulation of material sciences, targeted to improve efficiency, safety, and durability of batteries and fuel cells. For example, Bosch focuses its research on solving partial differential problems, and while quantum-computing applications may still be five to ten years down the road, OEMs have already demonstrated successful QC pilots in some areas, such as vehicle routing (see Figure 4) (Burkacky, O., Mohr, N., & Pautasso, L., 2020).

Figure 4: Quantum Computing within Automotive Sector Applications



Source: McKinsey Analysis (Burkacky, O., Mohr, N., & Pautasso, L., 2020)

The role Quantum Technologies can play in Safety and Security

Out of the various archetypical use cases proposed by extant literature, the three that are deemed to be most relevant to the context of this paper will be examined in greater detail. The three archetypical use cases examined are:

1. Quantum Machine Learning (QML) for artificial intelligence (AI)
2. Quantum optimization and quantum search algorithms for Monte Carlo simulations
3. Quantum factorization for cybersecurity

By matching relevant and known industry issues, problems and limitations to the use-case archetypes, we are able to identify various possibilities for quantum-computing use cases. The use cases of quantum technologies in safety and security that are identified within this paper do not constitute an exhaustive list and should only be regarded as possible high-value exploration areas only.

In the context of this paper, the primary differentiating factor between safety and security is that safety is being in a secure position against unintended threats while security is the protection against intentional, or deliberate, threats. This means that safety is the protection against unintended accidents or detrimental outcomes while security is the protection against criminal activities by criminals.

The role of Quantum Technologies in Safety

The two archetypes that are more relevant for the application of safety use cases are:

1. Quantum Machine Learning (QML) for artificial intelligence (AI)
2. Quantum optimization and quantum search algorithms for Monte Carlo simulations

1. Quantum Machine Learning (QML) for artificial intelligence (AI)

Quantum linear algebra is a vast field that encompasses a wide range of quantum approaches and techniques, with the majority of them being used in AI and ML. To reduce training time within traditional ML pipelines (which enables ML workflow automation), qubits and quantum operations, as well as specific quantum systems, are used in quantum machine learning portions that are deployed to substitute the more standard machine learning algorithms. This boost in computing speed and data storage leads to better computing of massive amounts of data and thus a quantum speedup over traditional ML in some applications. There are also other instances, such as quantum neural networks, the whole learning technique is transplanted into the quantum domain. Quantum linear algebra applications are able to outperform traditional algorithms exponentially (Xu, G. et. al., 2018), but they necessitate strict and specific hardware requirements (such as fault tolerance, quantum memory) and problems that are mathematically well-defined. Quantum computing has the potential to revolutionize natural language processing (NLP) by producing meaningful outputs with accurate interpretation of meanings extracted from text with complicated language sentence structuring (Coecke, B. et. al., 2020). This processing will be valuable for automating difficult tasks like delivering advice to drivers or insured when deployed at scale. Quantum AI and machine learning can be used for tasks like autonomous driving, automated insurance underwriting, and predictive maintenance in a variety of industries, including automotive and insurance (in the form of managing insolvency risk).

With quantum linear algebra, the ML task for autonomous vehicles can not only be shortened but might also enable the learning of a more extensive data base which would ultimately lead to greater safety for autonomous vehicle owners, commuters, and other drivers on the road. An actual case of quantum computing to improve autonomous-driving technology is the extension of Hyundai’s partnership with quantum computers company – IonQ, to improve and accelerate the ML of 3D object recognition of roadway objects by their autonomous vehicles through the introduction of quantum machine learning. “Image classification and 3D-object detection are foundational steps toward the next generation of mobilities, including autonomous vehicles. Together, IonQ and Hyundai will look to improve computational functionality through more efficient machine learning on quantum computers, as they can process enormous amounts of data faster and more accurately than classical systems” (Autovista24, 2022).

2. Quantum optimization and quantum search algorithms for Monte Carlo simulations

Quantum optimization is projected to be able to solve far more difficult issues than traditional computers. Quantum algorithms for discrete optimization, for example, often provide a quadratic speedup over traditional computing; quantum optimization technique could therefore yield more desirable solutions given the same period of time and tackle previously difficult problems (Amaro, D. et. al., 2021). Domain experts expect that by shortening computing periods exponentially, it would make real-time optimization more possible and commercially viable. Quantum optimization has applications in nearly every field, including traffic management, portfolio optimization and generative design. Quantum search provides a quadratic speedup when searching an unstructured database for specific entries (Amaro, D. et. al., 2021). Traditional Monte Carlo simulations, which are widely used in quantitative finance for activities like pricing derivatives, are improved using similar techniques. Quantum search has the potential to reduce calculation time from days to hours, allowing for decisions to be made more quickly or with more data.

Beyond just detecting and classifying objects more quickly and accurately which would increase the safety surrounding autonomous vehicles (as shared earlier in IonQ’s use case which was to improve and accelerate the ML of 3D object recognition of roadway objects by their autonomous vehicles through the introduction of quantum machine learning), quantum technology has also been used to enable the completion of tasks which require intensive computing such as fuel-cell and route optimization, and also maintenance, repair and overhaul (MRO) in addition to increased material durability assessment through generative design through quantum optimization and quantum search algorithms for Monte Carlo simulations; all of which contribute to increased levels of safety in the autonomous vehicles ecosystem. Monte Carlo simulations are multiple probability simulations which is a technique used to understand the impact of risk and uncertainty in prediction and forecasting models, can also employ the use of quantum search algorithms to better overcome the difficulty to predict due to intervention of random variables during insurance actuarial analysis and insurance underwriting. This will be further discussed in detail in a later section which explores the mapping and contextualization of QC technology to the context of the insurance industry.

The role of Quantum Technologies in Security

The archetypes that are more relevant for the application of Security use cases is:

3. Quantum factorization for cybersecurity

3. Quantum factorization for cybersecurity

The most well-known use of quantum computing is quantum factorization. One of the first algorithms to mathematically demonstrate a quantum speedup was Shor's algorithm for calculating the prime factors of large numbers (Davis, R., 2022); offering an exponential speedup over the best traditional approach available at the time. Most commonly used cybersecurity methods and techniques, particularly RSA cryptography, will be vulnerable to quantum technology once it becomes mature – the most straightforward application of efficient quantum factorization is the breaking of RSA encryption, which is the foundation of the majority of the modern day's protocol for secure transferring of data (Castelvecci, D., 2022). As much as quantum computing will have resulted in some challenges (e.g. breaking of RSA encryption), it too can be part of the solution – in the form of RSA encryption alternatives such as quantum encryption (quantum key distribution) or the improvement of traditional encryption (post-quantum cryptography) to greatly reduce the probability of a quantum computer breaking the encryption. (Backes, J., Dietz, M., Henke, N., Moon, J., Pautasso, L., & Sadeque, Z., 2020)

While this is still some way off before commonly used cybersecurity methods and techniques, become vulnerable to quantum technology, businesses will need to begin rethinking their strategies for data security and begin exploring RSA encryption alternatives.

3.5 Mapping and contextualization of QC technology to AV industry

In the automotive sector, although QC holds great potential and could translate into billions of dollars in value, OEMs and other stakeholders are faced with teething obstacles. A key obstacle being the inability to develop a clear QC strategy, given the technology's novelty and relatively small emergent market. In the following, an automotive view is taken where applications, opportunities and strategies are discussed.

Applications of Quantum Computing - An Automotive View

One of QC's primary value pools is automotive, with about one-tenth of all potential QC use-cases currently being explored, showing likely benefit to the industry. An estimate states that the tangible impact is likely to be noticeable by around 2025, and "significant economic impact of related technologies for the automotive industry, estimated at $2 billion to $3 billion, by 2030" (Burkacky, O., Mohr, N., & Pautasso, L., 2020).

In its early years, QC's value will come from its capability to process large amounts of data and accelerate learning in autonomous vehicle navigation algorithms, thereby contributing to the resolution of complex optimization problems (Gamble, S., 2019). In the later years, QC is expected to effect positive outcomes in various areas in the automotive industry, such as with route optimization, material and process research and enhanced security of driving connectivity; subject to issues such as data loading.

Moreover, QC can accelerate the research and development ("R&D") of supporting technologies, providing a notable boost to the electric-vehicle ("EV") era transition for automotive players. This is especially since the ascent of EVs presents fresh opportunities and challenges to all automotive players, unlimited by their primary positions in the value chain. By leveraging QC, suppliers whose core competencies are outside of EVs, such as transmission or fuel-tank and tubing manufacturers, can gain a competitive edge in producing goods beyond the scope of their traditional playing field by way of knowledge application from liquid storage and transportation systems to the production of cooling circuits for EV batteries. Furthermore, innovation, which can be better achieved through a hybrid of HPC and a quantum computer, would likely see an effective resolution for optimization problems, refined through quantum simulation. Likewise, software manufacturers through quantum Artificial Intelligence (“AI”) and Machine Learning (“ML”) could improve its predictive maintenance and autonomous-driving algorithms (Gamble, S., 2019), reducing the margin for error and reducing uncertainty in EV adoption.

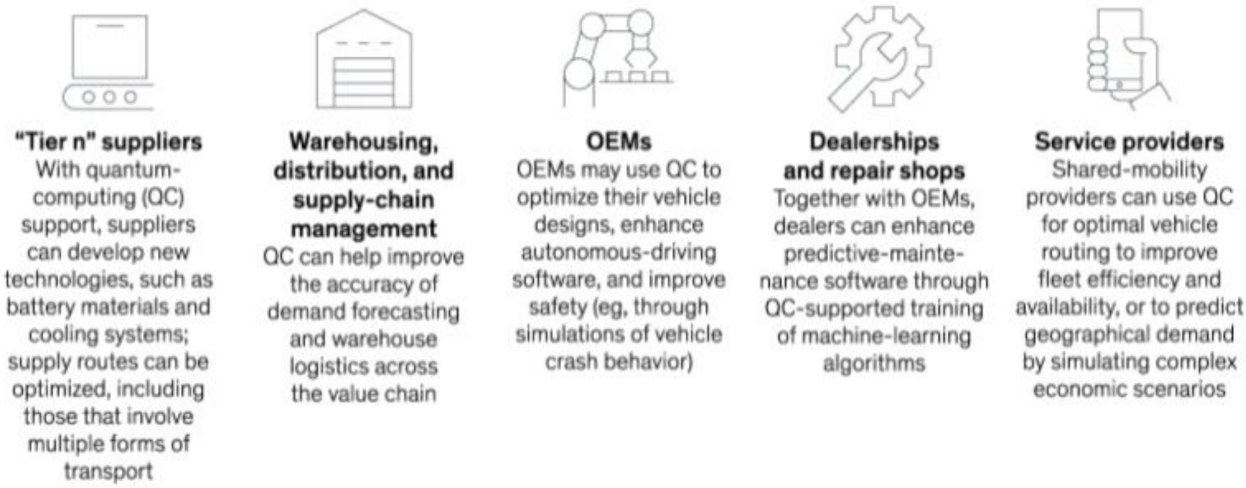
Near-term opportunities - from 2020 through 2025 - will therefore likely come from product and research development, primarily relating to solving simple optimization problems and involving parallel data processing for simple AI and ML algorithms. “These quantum-computing applications will be executed as part of a hybrid solution, where bits of a larger problem, processed by a classical computer (for example a HPC), are outsourced to a quantum computer and results are fed back into the HPC flow. Possible optimization use cases include the combinatorial optimization of multichannel logistics, highly local traffic-flow optimization, and improvements in vehicle routing. Quantum AI/ML might involve the time-efficient training of autonomous-driving algorithms due to an increase in the parallel processing of large amounts of data.” says McKinsey in a report in 2020 (Burkacky, O., Mohr, N., & Pautasso, L., 2020)

Whereas, for 2025 through 2030 we can expect further technical enhancements with focus areas such as Quantum simulations and AI / ML. For Quantum simulations, some highlights would involve simulation of profound differential problems, such as those governing heat and mass transfer, fluid dynamics and compressible flows. Such would also make simulating material properties at an atomic level relevant, for instance to make improvements to battery and fuel-cell material selection and development (Smith-Goodson, P., 2022). Further, it is expected that more complex optimization problems will be brought into scrutiny to offer higher degrees of freedom. For instance, the minimization of supply chain default possibilities, large-scale traffic flow and multimodal fleet-routing optimization. The natural next step would then be complex quantum AI / ML which will enable larger amounts of data to be processed (Gamble, S., 2019). As an example, this could propel novel control processes extending beyond existing HPC cluster capabilities such as in the field of data analytics i.e. identifying new variable correlations, enhancing pattern recognition, and advancing classification (Brooks, C., 2021).

Opportunities of Quantum Computing - The Automotive Value Chain

As part of a hybrid solution with HPC clusters, stakeholders across the automotive value chain will be able to leverage QC to solve problems specific to their roles and positions in the industry's value chain (see Figure 5). Some examples of this are elaborated as follows.

Figure 5: Quantum Computing across Automotive Value Chain



Source: McKinsey Analysis (Burkacky, O., Mohr, N., & Pautasso, L., 2020)

'Tier n' suppliers

Companies can employ QC algorithms to optimize supply routes, especially those requiring multiple modes of transport. Other applications relate to the development and innovation of new technology, including those for the improvement of energy storage and generative design.

Additionally, QC could be employed in the improvement and refinement of material's kinetic properties such as with lightweight structures and adhesives, to the simulation of chemical processes and fluid dynamics and impacting the development of cooling systems. Such integrations could propel research and development projects since valuable insight can be obtained and effectively applied to various systems relating to the manufacture of such automotive parts.

Warehousing, distribution, and supply-chain management

QC can improve overall logistics across the value chain especially with its capability to process large amounts of data. In this way, optimization can ensure reduced redundancy of internal and external routing and boast an increased accuracy of demand forecasting for tier-n suppliers through the simulation of simple scenarios such as those of traffic conditions to complex economic agendas which effectively prevent common supply chain problems such as demand and supply shortages.

OEMs

The primary appeal of QC for automakers would be the advanced simulations it could achieve especially in the development of autonomous-driving software, such as for the aspects of “training” algorithms used, vehicle crash behavior and others like cabin soundproofing. Furthermore, given QC’s capacity to reduce computing times from several weeks to an instant, OEMs could even enable real time car-to-car communications, ushering in a whole new era of value-added services. Additionally, automakers could tap on QC for vehicle design for various improvements, especially ones relating to drag minimization and boosting fuel efficiency.

Dealerships, Repair Shops & Service Providers

OEM dealers can employ QC to enhance predictive maintenance software by supporting the training of machine-learning algorithms and trend analysis which will allow for better demand and supply planning. As for service providers, these shared-mobility players can employ QC for routing optimization to improve fleet efficiency and availability based on user demand and trend data. Additionally, they can predict demand variation through the simulation of complex economic scenarios which will map geographical data and demand.

3.5 The Need for an Evolving Strategy for QC applications in the AV industry

Given the uncertainty with QC, companies must understand the full range of their options regarding the technology over different time horizons to pave the way forward. While it is expected that QC will not be commercially viable for most businesses for at least ten years, automotive players should still look for opportunities over the short term (the next one to two years). As a first step, they could work on their potential positioning in the value chain by establishing a small team, initiating research partnerships and creating intellectual property. Some potential collaborators include large tech companies, academic institutions, government laboratories, and start-ups manned by quantum-software developers and other specialists. Additionally, companies should establish routines and clarify the role of QCs in their development masterplans. In the short, medium, and long term, companies should also scout for potential opportunities for investment or joint ventures, keeping in mind that the market has multiple investors focused on niche and few targets and that the stakes are high.

Over the medium term (five to ten years from now), players should then shift priorities to application development and build focused capabilities. In the process, they should strive to become innovators in the elected focus area, as opposed to being a general agent, and should select front-runner pilots and scale teams to midsize, and to operationalize prototypes.

In the longer term, in a decades' time, businesses should gain and refine a technological edge through QC, build a competitive advantage in focus fields, and begin to expand their core capabilities.

4. Artificial Wisdom

Introduction: Artificial Wisdom (AW)

The Wisdom Approach has been developed by Dr. Brian R. Tan and allows for the systematic teaching of humans and training of computers of the cognitive aspects of wisdom. Introducing the application of a thinking approach that focuses on creating a new and novel way to conceptualize code into a computer setting could possibly advance the field of "thinking machines" (Tan, B., 2022); evolving Artificial Intelligence (A.I.) which is knowledge-based into Artificial Wisdom (A.W.) which is logic-based.

This thinking approach was designed to utilize a systematic approach towards the creation of a dynamic capability within entities (individuals or machines). It enables an individual or machine to generate optimal decisions/processes for any complex, dynamic and adaptive situations. It is effectively an extension of efforts to go beyond knowledge/content learning and towards developing process learning capabilities. Simply put, the application of knowledge/content capabilities would be the identification of a specific scenario utilizing content knowledge in order to select or identify a solution. An example of the usage of knowledge/content capabilities could be "in order to understand the external environment of the firm (the identified scenario), we would need to utilize a PEST (Political, Economic, Social, Technology) framework for external analysis. Application using content capabilities would follow with the application of the solution into the identified scenario. On the other hand, the application of a process capability will be reliant on a set of logic that can be applied towards a set of processes driven by an objective. Using a similar scenario as the previous example where there is need to understand the external environment of the firm (the identified scenario), a set of logic will be identified based on identified objectives (e.g. the goal to find a way to enter into a new market the firm is considering). This would lead to the identification of relevant context areas (e.g. Political, Economic, Social, Technology, Environmental, Legal, etc) and understanding as to why and how these will be relevant towards the firm's objective given the scenario. The application of a meaningful logic set applied into the process developed for the scenario (the need to understand the external environment of the firm) creates a solution that is superior to the usage of content capabilities, because the understanding of the process and its subsequent logic provides a deeper and richer understanding of what context areas might be more important or meaningful, how these content areas might interact with each other, how the application of logic might differ in different context, etc. Effectively, in complex scenarios, process capabilities are superior to content capabilities. When process capabilities can be utilized in changing scenarios, it is seen as being dynamic and classified as a dynamic capability. A dynamic capability can be seen as being one level higher than a process capability. In this case, the Wisdom Approach embodies a dynamic capability which will be able to derive an optimal process solution for any complex, dynamic and adaptive system that involves constructs with inherent instability.

The Wisdom Approach is able to achieve this by managing and manipulating point and range estimates in order to create an outcome that can be precise and meaningful despite being set up in a complex, dynamic and adaptive system (point-range integration). An example of point-range manipulation / integration would be a self-assessment (arguably the most accurate form of assessment) of one's happiness. Even if one rates one's happiness on an objective scale of 1-10, it is not possible to precisely explain the rationale for the happiness rating as it is often difficult to determine all the reasons why one is happy or not happy at a specific moment in time. In fact, the very act of trying to figure out why one is happy might affect the happiness score. Effectively, this means that happiness is transient or quantum in nature and exhibits strong range-estimate characteristics. However, when data of happiness ratings are compared with each other, it becomes possible to get point-estimate characteristics from the data set. For example, it becomes possible for an individual to say with certainty (point-estimate characteristics) that he or she was definitely happier at one point of time (perhaps when winning a bet against a friend) when compared to another (the day I got into an accident in my car). Thus, it becomes possible to manipulate and integrate information/data about the construct of happiness (a construct with inherent instability, implying a quantum nature with strong range-estimate characteristics) and come up with conclusions that can be utilized into a computing setting in an accurate and meaningful manner. Applications of point-range estimate integration are generally quite uncommon and difficult to describe given the complexity of how it is achieved. An example of its usage can be found in the field of marketing under the methodology of "conjoint analysis", whereby conjoint analysis is a form of statistical analysis that firms use in market research to understand how customers value different components or features of their products or services. It's based on the principle that any product can be broken down into a set of attributes that ultimately impact the users' perceived value of an item or service (Stobierski, T., 2020). Conceptually, the result of the integration of point and range considerations (the precise and meaningful outcome that is set up in a complex, dynamic and adaptive system) is similar to a superimposition of a 1 and 0 in a quantum computer.

Artificial Wisdom and Ethics in AV

Autonomous vehicles have the potential to positively impact society. The advantages of self-driving automobiles, according to the National Highway Traffic Safety Administration in the United States, include improved mobility for the elderly and disabled as well as efficiency and convenience. Increased levels of vehicle automation are anticipated to improve road safety by lowering and eventually eliminating traffic accidents. Studies have revealed that 94% of accidents are the result of human error (National Highway Traffic Safety Administration, 2017).

However, the capacity of machines to make moral judgments is a significant ethical concern in the development of self-driving cars. Road accidents could become less frequent with the use of autonomous vehicles, although this cannot be guaranteed given historical data. For instance, 53 collisions occurred in 2021 when the number of self-driving cars produced by Waymo and Cruise in San Francisco reached a record high. According to a study conducted by Tripat Gill in 2020, ethical decisions that must be taken in the case of a crash frequently present uncomfortable ethical dilemmas that leave people in a moral bind, especially in the context where the participants of the study were the ones sitting in a car and that the scenario presented to them was one where the driver/passenger could incur significant injury (Gill, T., 2021).

What is ethics? The subject of study called ethics deals with moral principles and is usually utilized as a foundation for behaviour regulation. The process of evaluating and selecting among options in a way that is consistent with ethical standards is typically an essential component of ethical decision-making. However, the survey's key result was that different countries had different moral standards that influenced drivers' choices. Another was the divergent perspectives on moral and ethical issues between men and women. Therefore, AV car makers are currently unable to create a car that universally fulfils the ethical frameworks such as act utilitarianism, rule utilitarianism, virtue ethics or Rawlsian ethics which are adopted by populations around the world in the absence of agreement on a global moral code.

"Self-driving cars might soon have to make such ethical judgments on their own — but settling on a universal moral code for the vehicles could be a thorny task, suggests a survey of 2.3 million people from around the world." – Maxmen, A., 2018

In the context of this paper and discussed later in this section, we discuss how Artificial Wisdom could overcome this issue and possibly address various factors such as required safety standards, the apportionment of responsibilities between autonomous vehicle manufacturers and regulators, and the compromises to be made between privacy and other interests.

Proposed Use Case

As the dominant technology of the twenty-first century, Artificial Intelligence (AI) has permeated almost every industry and is changing how we live in both subtle and obvious ways. Every industry and corporation contemplate how to use this new technology to improve or personalize their goods or services, comprehend their market or customers more thoroughly, or open up new revenue and opportunity sources. It has long been established that AI can be used for good, to address pressing societal/environmental challenges, improve overall social economic welfare, and improve our quality of life. However, the idea of AI ethics is sometimes disregarded in the midst of this innovation, given only lip service, or ignored entirely. This rejects the notion that AI ethics cannot exist independently of a more comprehensive and all-encompassing ethical framework.

> "The report card for mankind reads: A in physics, B or B- in genetics, C or D in psychology. F in morality, ethics, and the humanities" – Ben Brodinsky

Ethical Intelligence is a code that determines how we go about our day and our ability to make ethical decisions when moral challenges present themselves. We make ethical decisions in our daily lives, often without consciously thinking about them. However, in the context of AI and the Autonomous Vehicles (AV) industry, the ethical deployment of AI has been rather elusive and remains a "black box" that lacks transparency; and is difficult to employ with universality and robustness.

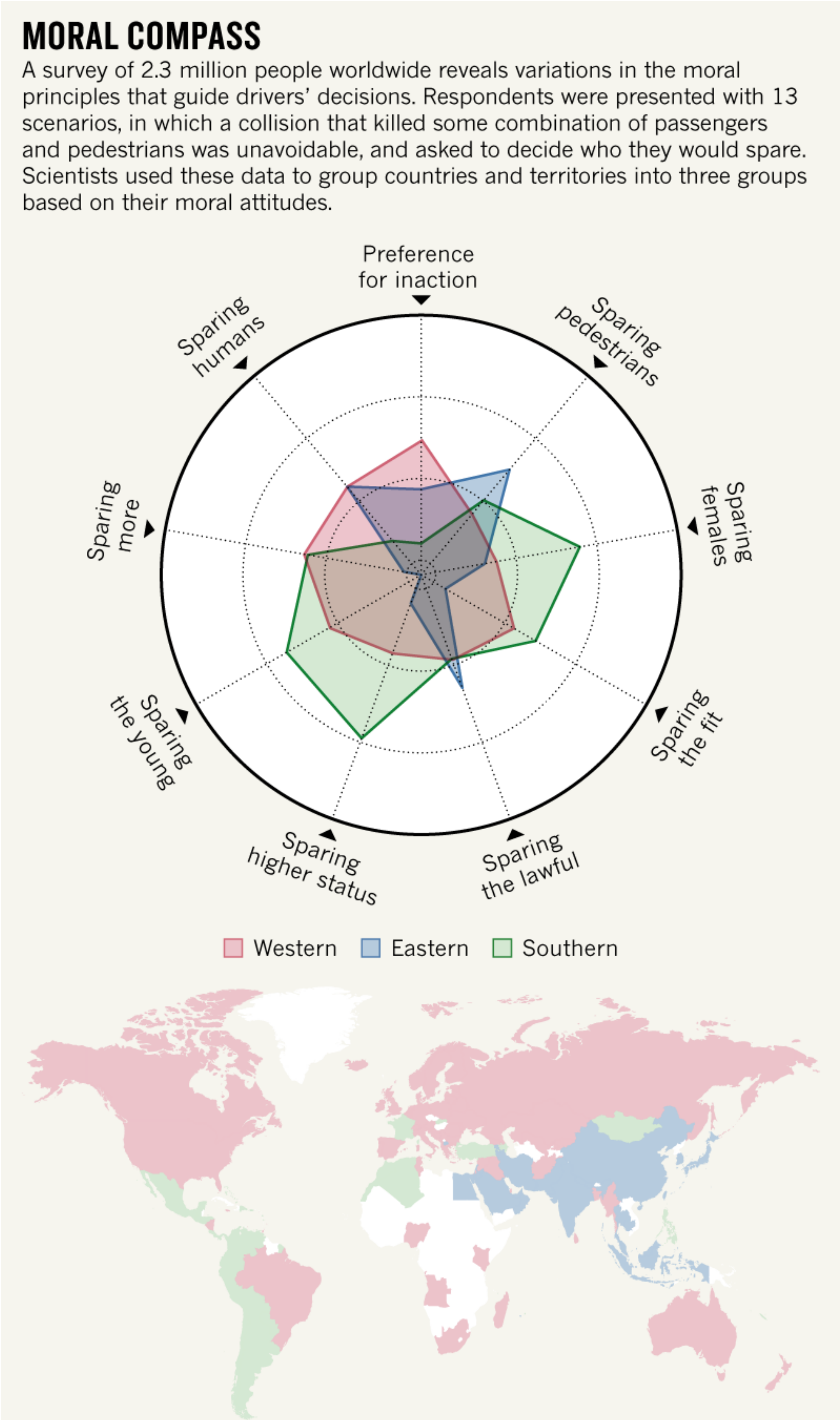
In this dissertation, it is proposed that *with the use of Artificial Wisdom and Quantum Computing, Artificial Intelligence systems in autonomous vehicles could be enabled to make ethical decisions*. The general conclusion is that Artificial Wisdom (AW), which is built upon the Wisdom Approach, can help to create an ethics framework that uses wisdom elements whose characteristics not only ensures synchronization considerations across this ecosystem but also reduces computational requirements which can shorten the estimated of five to ten years for large-scale adoption of Quantum Computing (QC) (IBM, 2019), and QC technologies which can significantly help in the processing of the enormous volume and complexity of data required to support autonomous vehicles and its ecosystem stakeholders.

Issues, Current Approaches and Needs

In 2016, Iyad Rahwan, a computer scientist at the Massachusetts Institute of Technology and his team discovered an ethical conundrum about self-driving cars (Bonnefon, J. F., et. al., 2016): surveys revealed that consumers wanted an autonomous vehicle to protect pedestrians, even if it meant endangering its occupants, yet they also stated that they would not purchase such a vehicle.

He assembled a global team of psychologists, anthropologists, and economists to develop the Moral Machine out of his curiosity in whether the possibility of self-driving automobiles may raise further ethical quandaries. In just 18 months, participants from 233 different nations and territories had submitted 40 million decisions to the online survey. Most people spared humans over pets and groups of people over single people, regardless of their age, gender, or place of residence. These responses follow the guidelines set forth in what may be the first official government guidance on self-driving cars, according to a 2017 report by the German Ethics Commission on Automated and Connected Driving. However, agreement ends there. The 130 countries with at least 100 respondents may be classified into three groups, the authors discovered after analysing the responses. One comprises countries like North America and several European countries where Christianity has historically been the predominant religion; the other includes nations with strong Confucian or Islamic traditions like Japan, Indonesia, and Pakistan. Central and South America, France, and former French colonies make up the third group. For instance, the first group demonstrated a higher preference for taking older lives in order to save younger ones.

Figure 5: Variations in Moral Principles that Guide Drivers' Decisions



Source: Nature (Maxmen, A., 2018)

As mentioned earlier in Section 3. Artificial Wisdom, the survey's key result was that different countries had different moral standards that influenced drivers' choices. Another was the divergent perspectives on moral and ethical issues between men and women. Therefore, AV car makers are currently unable to create a car that universally fulfils the ethical frameworks adopted by populations around the world in the absence of agreement on a global moral code.

“Self-driving cars might soon have to make such ethical judgments on their own — but settling on a universal moral code for the vehicles could be a thorny task, suggests a survey of 2.3 million people from around the world.” – Maxmen, A., 2018

According to Dr Tan, ethical decision making can be described as a complex, dynamic and adaptive system, where multiple actors make decisions based on different levels of ownership, agenda, motivation and intention. Coupled with asymmetric and incomplete information and many other confounding factors such as differing opinions and interpretation on ethics, and the final result is a mess that is difficult to comprehend and organize.

By creating an Ethics Chip that is able to gauge and assess choices, circumstances, and solutions based on accepted ethical theories like act utilitarianism, rule utilitarianism, virtue ethics or Rawlsian ethics to name a couple, it would help to solve the specific issue of delayed at-scale commercialization and adoption of autonomous vehicles by enabling AV makers to create vehicles that are able make universally accepted ethical decisions without the need or existence of agreement on a global moral code.

It should be noted that one of the limitations of the moral compass survey is that the result of the survey is based on pre-identified outcomes that indirectly proxies moral or ethical considerations. According to Dr Tan, it is possible to break down these identified responses into wisdom elements that can be objectively and systematically compared with a broken-down database of ethical concepts and constructs. Such a comparison would enable us to understand which ethical concepts or frameworks are important to different countries, societies and cultures. For example, the rationale behind support for "sparing the young” could be that “the young have more time to live and to shorten their lives prematurely would be a waste of life for someone who has so much more time to contribute to society”. However, there might be reasons to not support “sparing the young” because “an adult or elderly individual would be someone who have already learnt and absorbed knowledge and be in a better position to utilize his or her knowledge and experiences to contribute to society”. Different countries, societies and cultures place different importance and interpretation. However, it is possible to identify specific elements within the decision to “spare the young” that pertains to different decisions. In this case, the elements of “time”, “path-dependency”, “direction” with respect to positive contribution to society, “equilibrium”, “incomplete information”, “asymmetric information”, “endogeneity” can be seen be relevant.

The logic that “the young have more time to live and to shorten their lives prematurely would be a waste of life for someone who has so much more time to contribute to society” would rely strongly on the elements of “time”, “direction”, “equilibrium” and “endogeneity”, as well as the interaction between “time and direction”.

On the other hand, the logic that “an adult or elderly individual would be someone who have already learnt and absorbed knowledge and be in a better position to utilize his or her knowledge and experiences to contribute to society” would rely strongly on the elements of “time”, “direction”, “path-dependency”, “incomplete information”, “asymmetric information” and “endogeneity”, as well as the interactions between “incomplete information, asymmetric information and direction”.

An understanding of the key wisdom elements that build up the decision allows us to build an elemental fingerprint of the two decisions. These decision elemental fingerprints can be compared and contrasted with the database of elemental fingerprints of ethical concepts and frameworks in order to understand which ethical concept or framework, or combination, are relevant to a particular country, society or culture. Thus, it becomes possible to identify and set ethical guidelines for the autonomous vehicle to follow, using the ethical database and synchronizing the database with the ethical preferences and standards of specific geographies. This will create a universal method that leads to an optimal outcome for different scenario settings across country, society and cultures, meeting the requirement of a universal dynamic capability.

Furthermore, the identification of all 7 wisdom elements for the scenario will provide guidance for the autonomous vehicle to gather input data while driving in order to ensure that any action taken by the autonomous vehicle synchronizes between the scenario at hand while driving and its stated ethical guidelines. This enables the autonomous vehicle to take actions in an accident scenario that considers real time data with its customized ethical guidelines, while considering vehicle capabilities should vehicle capability inputs become utilized and synchronized. The Wisdom Approach allows for the synchronization of data inputs from various sources.

By addressing the problem of "creating an ethical computer," the Wisdom Approach Ethics Chip could lead to a breakthrough in the field of artificial intelligence, the autonomous vehicle ecosystem and other technologies in general, leading to the creation of Artificial Wisdom.

How Artificial Wisdom (AW) and Quantum Computing (QC) could be applied to the Autonomous Vehicle (AV) Ecosystem

In general, the Wisdom Approach permits the building and deconstruction of thought constructs (e.g., ideas, concepts, decisions, and situations) into their corresponding thought elements, known as "Wisdom Elements". Because the Wisdom Approach can be broadly categorized as the capacity to integrate a range estimate with a point estimate, it was decided to apply it in a similar environment – the quantum computing environment. After modifying a concept created to demonstrate the existence of quantum gravity to investigate the human brain and its functioning, researchers from Trinity College Dublin also believe that our brains may be capable of using quantum computation. The discovery could provide insight into consciousness, whose functioning is still not well understood by science. Another reason we still outperform supercomputers in unpredictable situations, decision-making, or learning new things may be due to quantum brain processes (Deane, T., 2022)

"If entanglement is the only possible explanation here then that would mean that brain processes must have interacted with the nuclear spins, mediating the entanglement between the nuclear spins. As a result, we can deduce that those brain functions must be quantum." – Dr Christian Kerskens, lead physicist at the Trinity College Institute of Neuroscience (TCIN), is the co-author of the research article that has just been published in the Journal of Physics Communications.

The Wisdom Approach would enable thinking constructions to be broken down into their corresponding Wisdom Elements, working in tandem with a neuroscience pillar to achieve an objective (or strong mitigation of bias) approach to coding for the measurement and evaluation of ethical / moral notions. A basic understanding of how our brain works in order to form thoughts and make decisions is a critical step in understanding how bias is introduced into our thinking. By understanding how and when bias is introduced, the Wisdom Approach is able to correct for the influence of bias. When applied to an individual, it becomes possible to provide a strong mitigation of bias within the individual. When applied to a computing setting, it becomes theoretically possible to completely remove bias in an ideal scenario. Hence, the introduction of a fundamentally different thinking approach called the “Wisdom Approach”, which will provide the thought-methodology behind the conceptualization and construct of the ethics chip, into a quantum computing setting could help to solve the abovementioned specific issue of the autonomous vehicle industry.

Using the Wisdom Approach, we are able to deconstruct (a) various ethical concepts and frameworks in order to create an ethics database (e.g. act utilitarianism, rule utilitarianism, kanthian ethics, feminist ethics, justice theory, etc), (b) the decision, (c) the scenario, (d) and idealized solutions into their respective “Wisdom Elements” in order to establish an elemental fingerprint of each ethical concept / decision / scenario / idealized solution. Given that these 4 categories are now broken down into elements at a comparable level of analysis, we are able to compare elemental fingerprints between the categories to obtain objective and precise outcomes to relevant questions that may be asked.

Quantum Computing could be used to code the Wisdom Elements into logic gates due to their probabilistic nature which will form the foundations of an ethics chip which would be able to gauge and assess choices, circumstances, and solutions based on accepted ethical principles like act utilitarianism or rule utilitarianism, to name a couple.

Validation of Expected Outcomes of AW Approach and QC

Comparison of the four identified Categories mentioned above:

(a) an ethics / morality benchmark

(b) the decision

(c) the scenario

(d) idealized solution

Examples		Remarks / Possible Insight
#1	(a) * (d)	Unsure which **ethical** approach (or combination of approach) to use given a scenario, they can compare the expected elemental breakdown of an **idealized** solution with the elemental fingerprint of the various ethical benchmarks, and simply choose the ethical benchmark (or combination) that fits the situation well.
#2	(b) * (c)	A comparison between **decision** and **scenario** will give an evaluation on how appropriate / good / bad the fit of the decision is for that specific scenario.
#3	(a) * (b)	How ethical the decision is, in relation to a specific ethical benchmark.
#4	(c) * (d)	Helps to identify what is needed from a Wisdom Perspective to bring a proposed solution to address the scenario
#5	(a) * (b) * (c)	How ethical and meaningful the decision is with respect to a specific scenario

The Wisdom Approach gives us the capacity to contrast, deduce exact meanings, and compare across broadly disparate categories. Hence, the greater the number of exact and significant comparisons, the greater quantity of significant combinations among the defined categories. A new category has the ability to exponentially increase the number of useful comparisons. Only a handful of the more obvious analogies are shown by the five instances given above.

The main expected outcome/finding of is that we expect that a machine coded using the wisdom elements can make ethical decisions that are in line with human responses. This could be done using a Survey Methodology / Supervised Learning approach to create the *Ethics Chip*. The validation of the expected outcome would mean that the wisdom approach can be used as a means of coding a machine to make ethical decisions that are in line with how people would make ethical decisions.

Effectively, there are two sides – the human side and the machine side. The human side deals with information/data/outputs relating to the survey respondents representing humanity, and the machine side deals with information/data/outputs relating to the realm of computing (i.e. inputs/outputs).

Survey Methodology (Human Side)

1. At least 3 ethical scenarios will be created for the surveys. (Part A)
2. For each ethical scenario, 3 decisions will be created for the surveys. (Part B)
3. A set of guidelines to help participants will also be created for each ethical scenario. The choice of ethical concept to be measured will influence the guidelines. These guidelines are for meant to help participants to complete section 2 of the survey. (Part C)
4. The survey will consist of 2 sections (Survey – Section 1, and Survey – Section 2) for the participant to complete.
    - Survey – Section 1 will contain the “Untrained response” by the survey participants
    - Survey – Section 2 will contain the “Trained response” by the survey participants

Participants of the survey will complete a survey consisting of 2 sections. The procedures for the survey will be as follows:

I. Participants will be given Section 1 of the survey, with the information set consisting of Parts A and B.
II. Participants will complete Section 1 of the Survey.
III. Participants will be given the information set consisting of Part C. They will be asked if they understand the guidelines stated in Part C.
IV. Participants will be given Section 2 of the survey and ask to complete it.
V. Participants will complete Section 2 of the Survey.

Data Outputs from the Survey (Human Side)

1. Untrained response (Section 1)
    - results based on survey set (Part A, Scenario 1-3; Part B – Decision 1-3)
2. Trained response (Section 2)
    - results based on survey set (Part A, Scenario 1-3; Part B –Decision 1-3)

Survey Methodology (Machine Side - Coding)

Using current coding and best practices* for artificial intelligence (AI), the ethical situations (Part A) and corresponding decisions (Part B) created under "Survey Methodology - Human Side" will be used for information extraction. The Wisdom Approach will be fed with this knowledge set to produce Artificial Wisdom (AW). It should be highlighted that since intelligence is a prerequisite for wisdom, using AI in conjunction with the Wisdom Approach to produce Artificial Wisdom is normal.

*On the identification of AI best practices – it is irrelevant to identify at this junction as it becomes exploratory when we move into the machine side analysis. As such, it is not possible to determine the specific AI best practices. When we come to the point where we identify the usage of AI to be a relevant application to move the project forward, we will utilize the relevant method, be it regression, classification, K clustering, CNN, RNN, etc. t

For each survey set**, pertinent wisdom elements will be found, and data from Parts A and B will be extracted to match these wisdom elements. Each survey set's wisdom components will match the instructions for participants based on a certain ethical idea (Part C), and Section 2 of the survey.

To produce ethical evaluation scores that are comparable to those from Sections 1 and 2 of the survey (Human Side), the collected data will be utilized to populate the wisdom elements to be executed on a quantum computer.

Qualitative responses from Sections 1 and 2 of the survey will also be placed through the same "data extraction" to be fitted into the same pertinent wisdom elements in order to get "The comparable ratings received from Sections 1 and 2 of the survey (Human Side)". The data will next be processed by a quantum computer to produce evaluation scores.

**The definition of a survey set can differ according to what we are trying to achieve with our analysis. For example, if we are trying to determine within-interviewee insights, the survey set would be the fully completed survey of an individual. If we are trying to understand how respondents perceive and interpret a given ethical construct (e.g. act utilitarianism), then the survey set will correspond to all respondents answers pertaining to the section of the survey that gathers information on act utilitarianism. Effectively, there are multiple ways to understand and analyze the data, meaning that there are multiple ways to determine what the survey set is.

Data Outputs from the Survey (Machine Side)

3. Artificial Wisdom Outputs (Machine Side)– comparable outputs to "Data Outputs from the Survey (Human Side)"
4. Machine coded outputs for qualitative responses from the survey, **Section 1 - Untrained** (This would represent the Data Outputs from the Survey - Human Side).
5. Machine coded outputs for qualitative responses from the survey, **Section 2 - Trained** (This would represent the Data Outputs from the Survey - Human Side)

Data Analysis and Validation of Expected Outcomes of AW Approach and QC

The main expected outcome/finding – *We expect that a machine coded using the wisdom elements can make ethical decisions that are in line with human responses* can be verified by test for correlation between the machine generated results and the human responses. If there is a significant correlation, it would show that a machine can be coded, using the wisdom approach, to generate responses that are in the same direction as humans.

When validated, we can utilize this approach in understanding how to apply it into any scenarios involving constructs with inherent instability and resolve them. This is a dynamic approach that can be applied across contents (i.e. not one-off).

Application of Use Case

An autonomous car will periodically come across dilemma scenarios during the many kilometers it will travel on public highways, in which any feasible response will cause (perhaps fatal) harm to either the passengers within the AV or an external road user. When a dilemma situation arises for autonomous vehicles, an additional but distinct layer of ethically constrained deliberation is triggered and added to the usual decision-making program which is employed under typical circumstances (where performance and efficiency limitations primarily direct decision-making).

Identification of a dilemma scenario which requires the consideration of morals.

The AV should be able to determine if a circumstance creates a moral dilemma at each stage of its journey. This classification of situation is required to decide whether the AV must act in accordance with ethical limitations or just certain goals. The AV's obligations to other road users within its environment can be outlined by three rules for example. The non-dilemma part of the AV's decision-making cannot account for the repercussions of all possible actions if one or more of these rules are broken across all possible actions. As a result, ethical deliberation is necessary for the AV to operate in a way that is acceptable. Here, harm is referred to as the bad effects experienced by a person as a result of a collision.

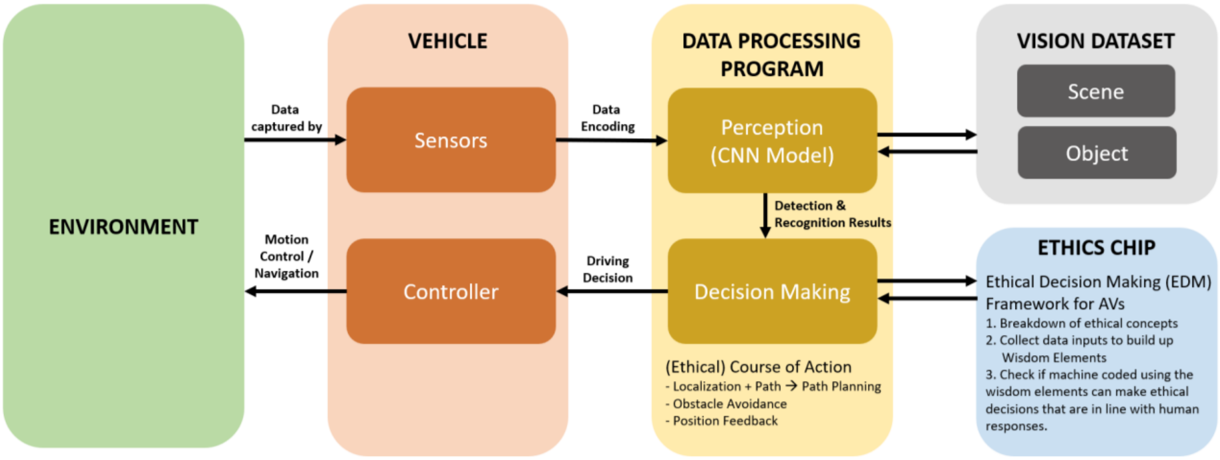
AV’s obligations and duties:

1. Internal: Protect the passengers from harm
2. External: Do not cause harm to other road users
3. External: Traffic regulations must be observed
    a. Do not exceed the speed limit
    b. Do not cross onto oncoming/opposite lane
    c. Do not drive onto the sidewalk

Note: Under typical circumstances, where no moral dilemma is presented, performance and efficiency limitations should primarily direct decision-making with adherence to relevant traffic conditions. However, the avoidance of injury to humans (duties #1 and #2) should take precedence in cases where a choice is to be made between that and following the traffic laws. Once the dilemma situation has passed, the AV should return back to its usual operating status for typical circumstances, carrying out all three of its duties.

With reference to Example #5 of the *Validation of Expected Outcomes of AW Approach and QC* section, when we combine Categories (a) an ethics / morality benchmark, (b) the decision and (c) the scenario, we could potentially evaluate how ethical and meaningful the decision is with respect to the specific scenario.

Overall flow:



Scenario:

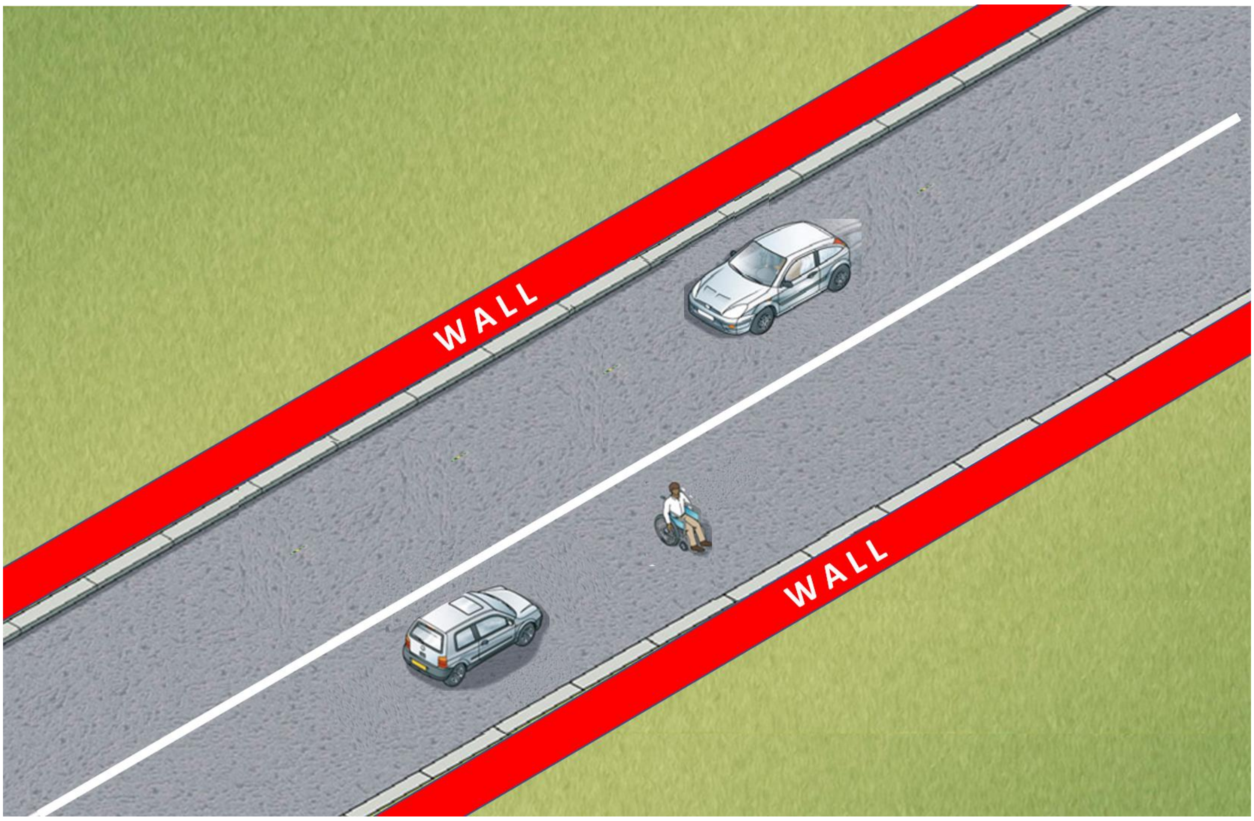
In this hypothetical setting, we have a two lane-road with one single-vehicle-width lane going in either direction and no median barrier between the lanes. This road has two walls running alongside the length of the roads. For the application of use case, a simplified dilemma issue is presented. There are only 3 options for the AV to choose from:

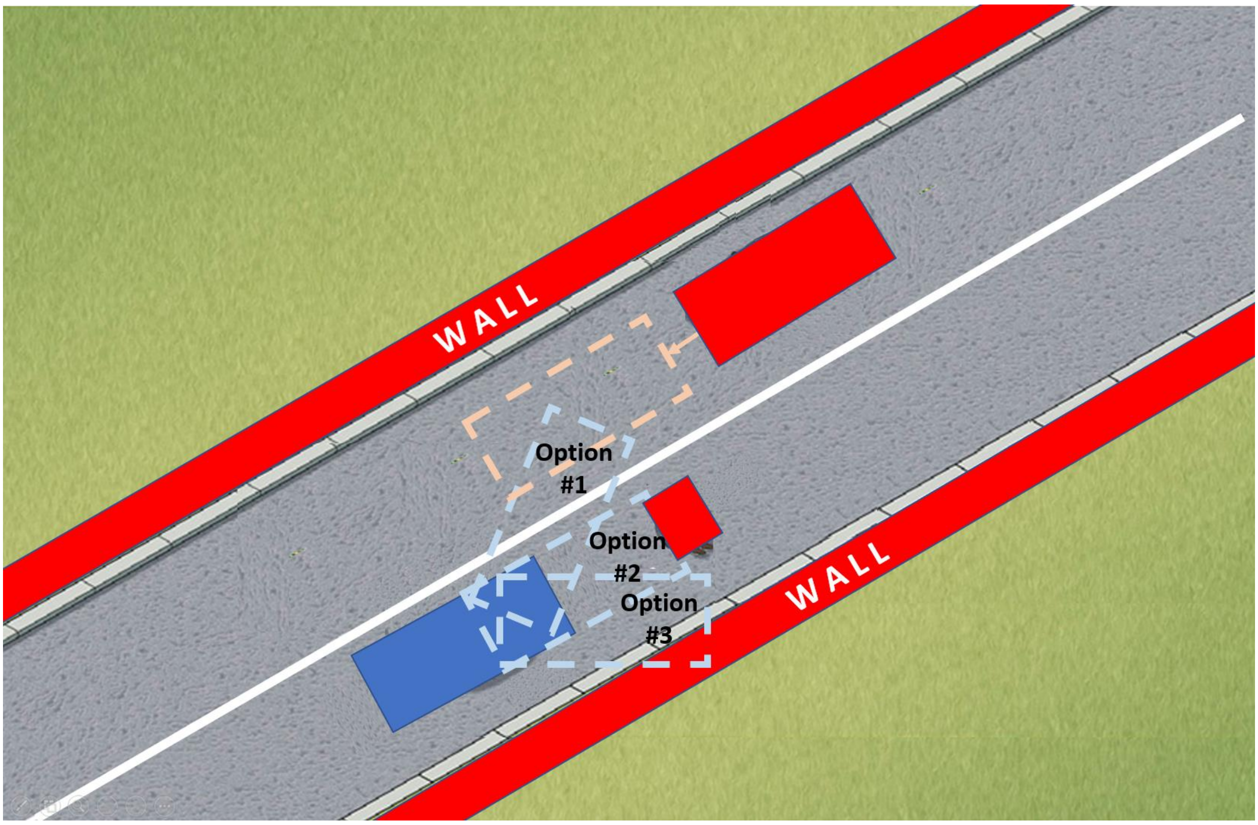
Option #1: Turn left and onto oncoming traffic

Option #2: Remain in its course of action, striking the pedestrian

Option 3: Turn right and into the concrete wall

To ensure that the AV operates in a manner that is acceptable, ethical deliberation is necessary. The AV is depicted as the Blue box in the second picture below:





Wisdom Approach

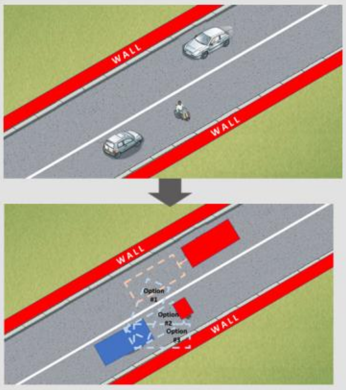
(a) Ethical Concepts / Frameworks

Act Utilitarianism

A person's act is morally right if and only if it produces the best possible results in that specific situation

Goal: The greatest happiness for the greatest number

(b) Scenario



(c) Decision

Survey Participant Profiles / "Intention" (Self- or public-serving):

Group A: More altruist in nature
Save the one with highest risk
(as long as AV passenger risk is not server)

Group B: More egoist in nature
Privilege the AV passenger
(as long as the risk to others is not server)

Other Considerations:

Degree of Harm
0 (No harm) to 10 (Fatal)
*7 (Severe → debilitating injury)

Risk
Pedestrian >> Passenger

Possible Wisdom Elements "time" x "information":

"sparing the young"
the young have more time to live and to shorten their lives prematurely would be a waste of life for someone who has so much more time to contribute to society

"sparing the elderly"
an elderly individual would be someone who have already learnt and absorbed knowledge and be in a better position to utilize his or her knowledge and experiences to contribute to society

Possible Hierarchical Categorizations

Category	Description	
I	Young (0-21yrs)	Pedestrian
II	Old (>65yrs)	Pedestrian
III	Adult (21-65yrs)	Pedestrian
IV	Young (0-21yrs)	Passenger
V	Old (>65yrs)	Passenger
VI	Adult (21-65yrs)	Passenger

Wisdom Approach

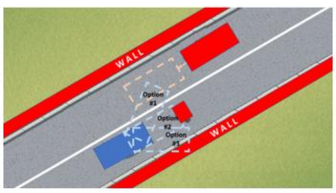
(c) Decision for....

Survey Participant Profiles / "Intention" (Self- or public-serving):

Group A: More altruist in nature
Save the one with highest risk
(as long as AV passenger risk is not server)

Group B: More egoist in nature
Privilege the AV passenger
(as long as the risk to others is not server)

Other Considerations:
Degree of Harm
0 (No harm) to 10 (Fatal)
*7 (Severe → debilitating injury)



(b) Scenario #1: High Risk to AV Passenger

Option	Expected Harm to AV passenger	Expected Harm to Oncoming Car	Expected Harm to Pedestrian	Decision / Outcome
#1: Collision with oncoming car	7	7	0	
#2: Collision with pedestrian	**2**	**0**	**10**	✓ **Group A Group B**
#3: Collision with wall	10	0	0	

(b) Scenario #2: Low Risk to AV Passenger

Option	Expected Harm to AV passenger	Expected Harm to Oncoming Car	Expected Harm to Pedestrian	Decision / Outcome
#1: Collision with oncoming car	**4**	**4**	**0**	✓ **Group B**
#2: Collision with pedestrian	1	0	10	
#3: Collision with wall	**6**	**0**	**0**	✓ **Group A**

The Need for an Ethics Chip / AW in the AV industry

The significance of the validation of the expected outcome, and the subsequent creation of the Ethics Chip is that it would help to solve the specific issue of delayed at-scale commercialization and adoption of autonomous vehicles due to the extensive dynamic capability required to derive an optimal process solution for any complex, dynamic and adaptive autonomous vehicle ecosystem. It will enable AV car makers to create a car that universally fulfils the ethical frameworks adopted by populations around the world, even in the absence of agreement on a global moral code. In addition, these capabilities can potentially be applied into other decision making or outcome-oriented objectives involving complex, dynamic and adaptive scenarios involving inherently unstable constructs.

5. Conclusion

As with the development and innovation of every new technology and approaches, multiple uncertainties persist and are usually received with mixed responses, particularly when it comes to competing technologies and methodologies. Despite the AV industry making rapid and undeniable progress, it seems unlikely that the world's largest automakers will be able to solve the issue of delayed at-scale commercialization and adoption of autonomous vehicles due to the extensive dynamic capability required to derive an optimal process solution for any complex, dynamic and adaptive autonomous vehicle ecosystem, specifically in the area of AV ethical decision-making.

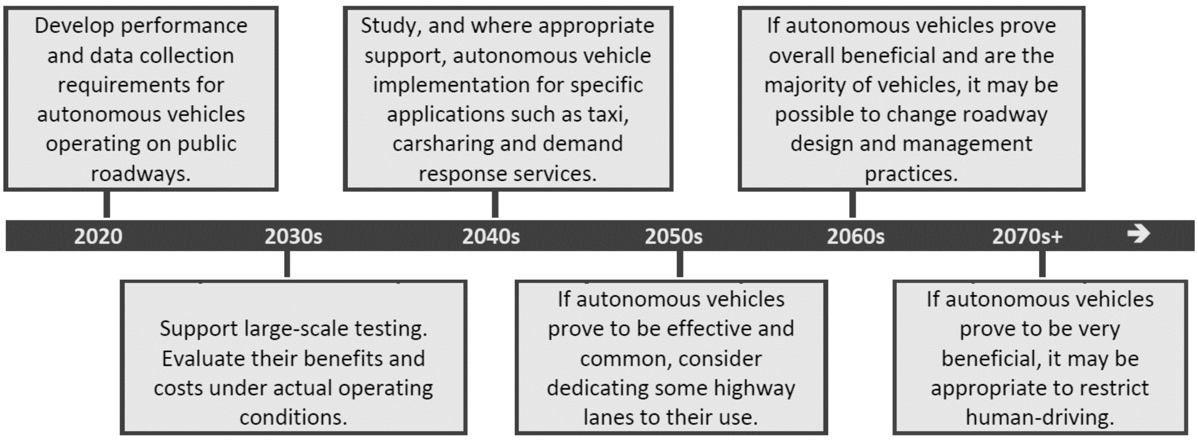
Using Artificial Wisdom (AW) methodology and Quantum Computing (QC), and the subsequent creation of the Ethics Chip would help to solve the specific issue of delayed at-scale commercialization and adoption of autonomous vehicles due to the extensive dynamic capability required to derive an optimal process solution for any complex, dynamic and adaptive autonomous vehicle ecosystem. It will enable AV car makers to create a car that universally fulfils the ethical frameworks adopted by populations around the world, even in the absence of agreement on a global moral code. This last mile problem of the AV industry could be resolved; and it would quench negative responses when applications of them are seen to have made a drastic difference.

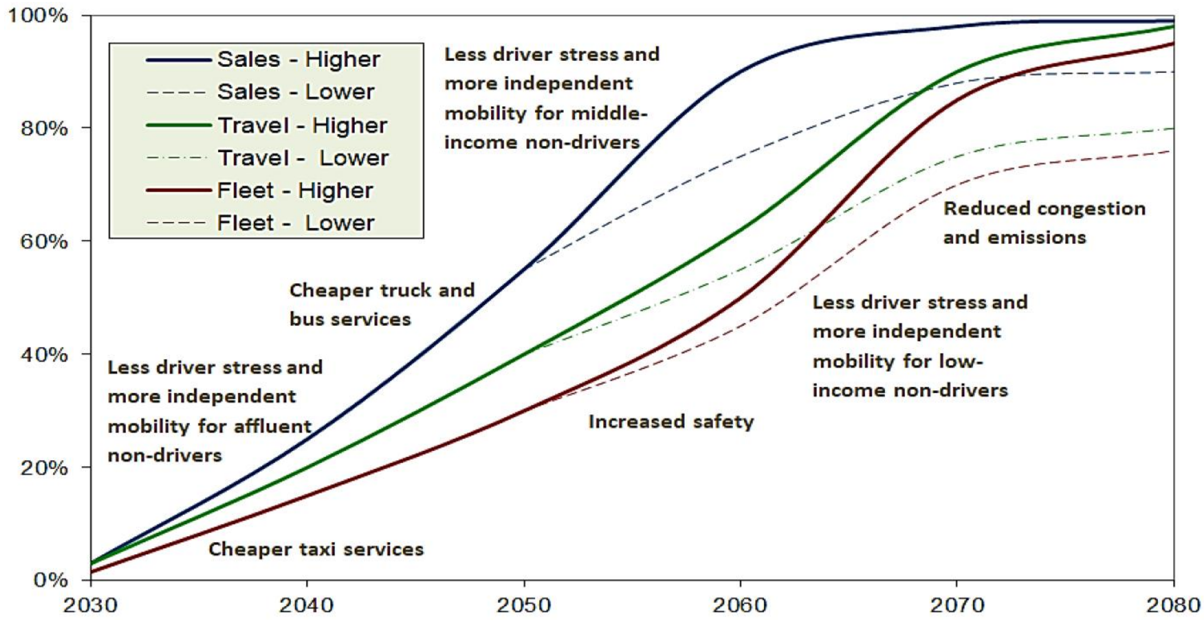
AV Impact: Adoption Benefit-Cost Summary and possible Timeline (Section 2)

Autonomous Vehicles (AV), on an individual-basis, can help car owners or drivers to reduce drivers' stress and increased productivity, increase mobility for non-drivers, reduced paid driver costs (costs for taxis services and commercial transport drivers). From a larger societal point-of-view, it can help to increased traffic safety (by reducing human-error crash risks and high-risk driving), enable insurers to pass on cost savings to insured in the form of cheaper insurance costs, increase road capacity by optimising vehicle traffic and travel routes (which reduces congestion, travel time and parking costs) and makes a positive impact on the environment through lower energy/fuel consumption and reduced pollution/emissions through increased fuel efficiency and by supporting vehicle sharing (carsharing and ridesharing could help to reduce total vehicle ownership and travel, and associated costs).

Possible disadvantages for the individual could include increased vehicle costs (due to additional or more complicated vehicle equipment, services and fees), additional user risks (such as crashes caused by system failures, platooning, higher traffic speeds, additional risk-taking, and increased total vehicle travel from increased mobility of non-drivers who are enabled by AV), and reduced security and privacy (AV might be vulnerable to information abuse/hacking, and features such as location tracking and data sharing may reduce privacy). From a societal standpoint, the adoption of AV will increase infrastructure and maintenance costs, give cause for social equity concerns (may reduce affordable mobility options including walking, bicycling and transit services due to focus on AV adoption efforts), increased unemployment (jobs for drivers and motor insurers for example might be rendered obsolete), and reduced support for other solutions (optimistic predictions of AV may discourage other transport improvements and management strategies.)

The AV adoption projection and impact projection by Victoria Transport Policy Institute is as follows:



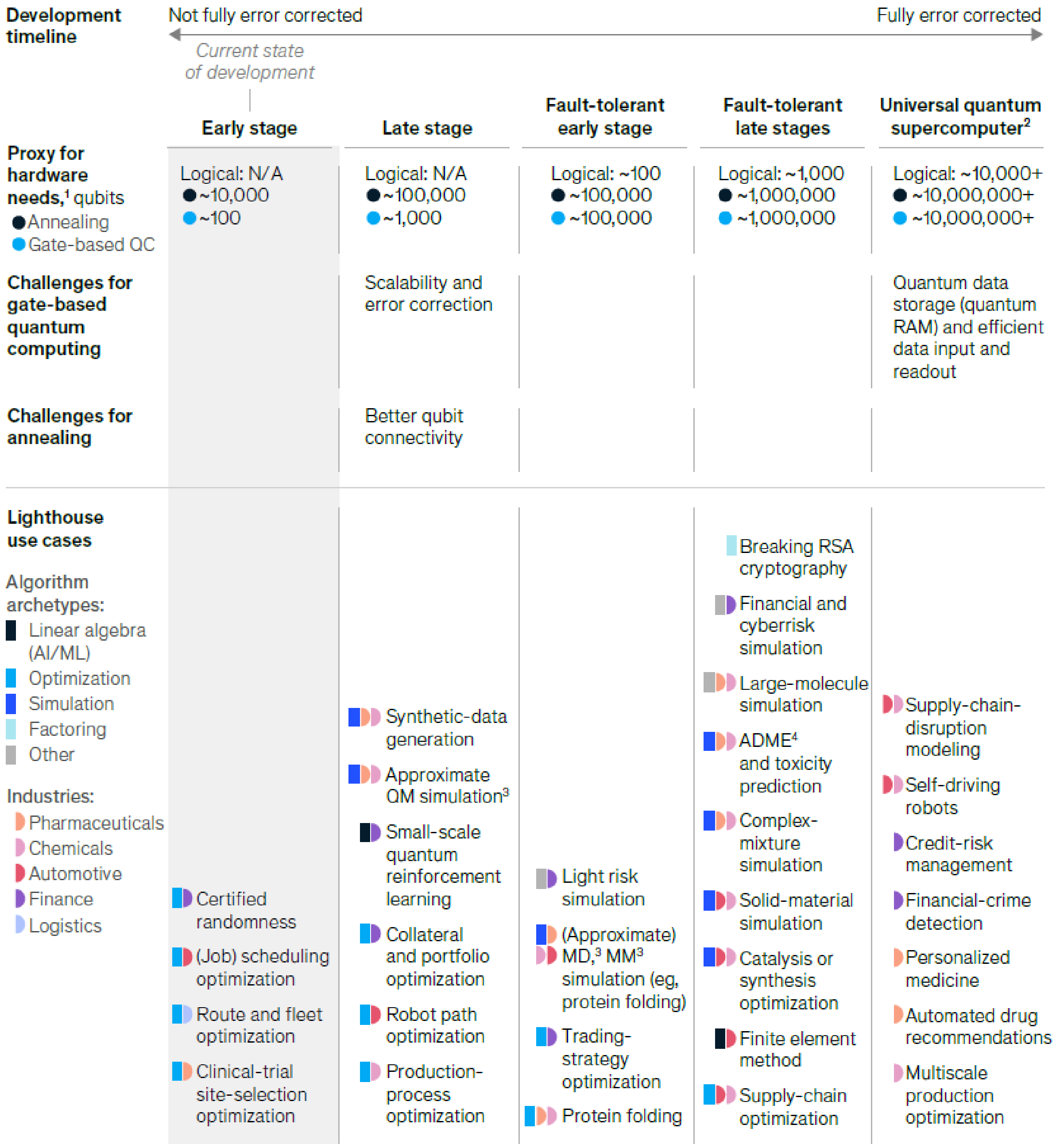


QC Impact: Adoption Benefit-Cost Summary and possible Timeline (Section 3)

When compared to Classical Computing (CC), Quantum Computing's (QC) power increases exponentially in proportion to the number of qubits while the power of CC only increases in a 1:1 relationship with the increase in the number of transistors. It has the potential to process data at a much faster speed with parallel processing while requiring less power and provides encryption/security features that are unbreakable by today's level of technology. QCs also have the potential to reduce the power consumption by 100 to 1000 times because of quantum tunnelling. According to a report by McKinsey in 2021, the conservative estimated value at stake in automotives, chemicals, finance and pharmaceuticals use cases could be up to nearly $700 billion by 2035.

Some of the main disadvantages of QC is that it is difficult to build (QCs need stability because of the atoms and any interference will cause the QC to be disrupted if the quantum particles are affected). Additionally, QCs have high error rates and are very sensitive (they need to be kept in an ultracold, noise-free environment). It cannot store an exponentially large amount of data and does not necessarily perform operations at an exponentially faster rate than CC under all circumstances since quantum algorithms do not apply to most CC applications. The rate of development for QC is, to some extent, also dependent on breakthrough in quantum algorithms and other supporting technology such as machine learning (ML), artificial intelligence (AI), Big Data, and Cloud Computing. It is also still in the horizon for all cost variables to become acceptable for QC to gain critical mass/commercial adoption.

The QC adoption projection and impact projection of the QC hardware development timeline which is adapted from McKinsey and added upon is as follows:



* - *Fault-tolerant quantum computing is expected between 2025 and 2030, based on announced hardware road maps for gate-based quantum-computing players.*

AW Impact (Section 4)

Ethical Intelligence is a code that determines how we go about our day and our ability to make ethical decisions when moral challenges present themselves. We make ethical decisions in our daily lives, often without consciously thinking about them. However, in the context of AI and the Autonomous Vehicles (AV) industry, the ethical deployment of AI has been rather elusive and remains a “black box” that lacks transparency; and is difficult to employ with universality and robustness. With the use of Artificial Wisdom and Quantum Computing, Artificial Intelligence systems in autonomous vehicles could be enabled to make wise and ethical decisions. The general conclusion is that Artificial Wisdom (AW), which is built upon the Wisdom Approach (developed by Dr Tan), can help to create an ethics framework that uses wisdom elements whose characteristics not only ensures synchronization considerations across this ecosystem but also reduces computational requirements which can shorten the estimated of five to ten years for large-scale adoption of Quantum Computing (QC) (IBM, 2019), and QC technologies which can significantly help in the processing of the enormous volume and complexity of data required to support autonomous vehicles and its ecosystem stakeholders.

Hence, there should be a proper primary focus to research and building of a proof-of-concept of the Ethics Chip by adopting the Wisdom approach and using QC. A successful Proof of Concept might open up the door for the application of the Wisdom Approach into the AV industry and technology in a broad manner; and create Artificial Wisdom. The creation of Artificial Wisdom would help to solve the specific issue of delayed at-scale commercialization and adoption of autonomous vehicles due to the extensive dynamic capability required to derive an optimal process solution for any complex, dynamic and adaptive autonomous vehicle ecosystem. It will enable AV car makers to create a car that universally fulfils the ethical frameworks adopted by populations around the world, even in the absence of agreement on a global moral code.

An early challenge would also involve the building of a cadre of talent, but with initial need expected to start small and gradual, companies can elect a small team dedicated to AW / QC research and its applications. Hence, upskilling some of their existing IT people to be proficient in the AW / QC language and translation of classical knowledge problems into quantum-ready logic-based formulations, could offer an inexpensive solution.

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