TRANSCRIPT

Eighth Annual National Security Conference

Robotics on the Battlefield: The Coming Swarm
June 11, 2014

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Robotics on the Battlefield: The Coming Swarm

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PAUL SCHARRE: Hi. I'm Paul Scharre. I'm director of the 20YY Warfare Initiative here at CNAS. There we go. That's what I was waiting on.

What I'd like to talk with you about today is an ongoing revolution in warfare. Now, militaries have always sought the latest technological advances in war, from the English longboat to the rifle musket, to the rifle optics and night vision goggles that I carried as I walked through the mountains of Afghanistan and the streets of Iraq. Today, we stand on the cusp of revolution in robotics. Robots are finding their way into factories, highways, our homes, and they will play a significant role on the battlefield.

The U.S. military has a lead in unmanned systems today but that lead is fragile. Experts estimate that by 2018, global defense spending and military robotics will top $7.5 billion a year. At that same time, global spending on commercial and industrial robotics will exceed $40 billion a year.

Now, the technologies that undergird U.S. military supremacy today, like stealth and GPS, came from the U.S. defense establishment. How does the U.S. military sustain its superiority when some of the most game-changing innovations will come from the commercial sector and will be widely available to everyone? Uncovering some of the most game-changing uses of that technology will be critical.

The U.S. military has used unmanned systems to great effect in the most recent conflicts. The thousands of air and ground robots patrolling the skies and defusing bombs, they have saved countless lives. U.S. military investment in unmanned systems has increased dramatically over the last decade but they are still relatively small as a slice of the overall DOD budget. Only one of out of every 20 R&D and procurement dollars is spent on unmanned systems.

Now, this would make sense if they were only useful in niche roles in the future, like reconnaissance or bomb disposal. In fact, as manned systems incorporate greater autonomy and approach true robotics systems, they will be increasingly useful in a range of missions in all domains on the battle space. Some have compared unmanned systems to where tanks and aircraft were at the end of World War One, where they had been used in a small way in that conflict, but their true potential on the battlefield that we've seen 20 years later, in World War Two with the advent of the Blitzkrieg.

But rather than just assert that's the case, what I want to do is walk you through some specific examples of challenges the U.S. military is facing and will face in the future and how unmanned systems can address those challenges.

Today, the U.S. military faces a range of emerging threats from state and non-state actors. These include long-range precision strike weapons that threaten traditional U.S. military power projection, anti-satellite weapons that target vulnerable U.S. satellites in space that move through predictable orbits, and precision strike weapons in the hands of non-state actors, like man-portable air defense systems, anti-tank guided missiles, and even swarms of low-cost drones that could be purchased commercially and outfitted with explosives could operate as flying IEDs. Unmanned systems could

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help address these challenges because their ability to take additional risk and they're longer endurance.

What I'd like to do now is walk you through some specific scenarios and give some examples.

U.S. fifth generation fighter aircraft are the best in the world but their diminishing numbers combined with the tyranny of distance means that they are likely to be outnumbered by potential adversaries in future conflicts. Unmanned systems can help address this challenge by bringing additional sensors and missiles into the fight at relatively low cost. This can be done because of their longer endurance. A single-seat manned fighter aircraft could stay in the air, the aircraft for long periods of time but the pilot for 12 to 14 and still remain combat capable. Unmanned aircraft, not tied to the limits of human endurance, can remain in the air with aerial refueling for 40 to 50 hours at a time. Now, what this means is that in order to sustain the same amount of combat power forward, fewer total aircraft are needed, saving billions of dollars.

In addition, they can be operated at a lower cost in peace time because costly flying hours will not be needed in the future to maintain the currency of pilots. Future unmanned aircraft will have flight controls that are increasingly automated as pilots shift to controllers. Without a seat of the pants feel to be gained from actually being in the aircraft, high-fidelity simulators can be used, saving costly flying hours for large-scale exercises and real world operations. And this also will save billions of dollars over the life cycle of a program.

The Air Force concept for this is called loyal wingman. It is captured in a visionary document released by the Air Force just this spring. However, the Air Force plan to build a next generation unmanned aircraft, the MQ-X, was cancelled in 2012. And like many examples that I'll walk through that disconnect between the vision and the funding is, of course, what will be the main limiting factor in this idea moving forward.

Similarly, U.S. destroyers are incredibly capable combat assets with the ability to project power from sea onto land with Tomahawk land-attack cruise missiles and ballistic missile defense ships have the ability to provide an umbrella for U.S. ships, bases, allies and partners anywhere on the globe against ballistic missile threats.

But they are limited in their magazine capacity. With only a limited number of vertical launching system cells with which to hold missiles, commanders must make difficult choices about the balance of offensive and defensive missiles before leaving port. And they ultimately risk having not enough of either. Now, the U.S. Navy is testing a low-cost per shot electromagnetic rail gun that could be a game changer for ballistic missile defense. The Navy will test this weapon at sea in 2016. And, if successful, it will allow the Navy to fire a large number of slugs at incoming missiles at very low cost.

Unmanned missile barges could also be used to expand the defensive and offensive striking capacity for existing ships at relatively low cost. Because there would be no people onboard, they need not be combat capable warships but would merely be extra-magazines for existing destroyers.

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In fact, commercial shipping companies have recently expressed interest in building larger unmanned cargo ships for commercial shipping. Now, this concept is new. Many countries around the globe are investing in small unmanned surface vessels but not large ones yet. But the commercial shipping industry is already starting to invest money in some of underlying technologies that might make this possible.

Unmanned aircraft can also be used to reach deep inside enemy air defenses and because of their longer endurance persist there for long periods of time. This will allow them to track hard to find mobile targets like enemy mobile missile launchers. They could autonomously jam enemy radars, employ non-kinetic weapons, like high-powered microwaves, and when they find those hard to find targets, reload those coordinates back to human controllers who authorize them for strikes.

The Navy is currently developing an unnamed carrier launched aircraft called U-class that will be the follow-on to the Navy's experimental X-47B aircraft that recently made an historic landing on an aircraft carrier. Now, lawmakers have recently expressed concern over the direction the Navy is heading with their U-class program because what the Navy is currently building is not this aircraft. The Navy's current plans call for a maritime surveillance aircraft that will not have the range, payload or stealth necessary to accomplish this mission. Now, the Navy will release their final requirements for their program later this summer so when they do so, we'll see if they're responsible to lawmakers' concerns.

Cruise missiles in the future will be increasingly networked and autonomous, which will enable U.S. forces to unlock the power of swarming. Now, a large number of missiles is not a swarm. That's a deluge. But networked cooperative autonomous systems can hold game-changing effects in the battlefield. They can allow the ability to attack target coordinated, simultaneously coming from multiple directions, and synchronizing electronic warfare attacks along with kinetic attacks with onboard sensors that can perform battle damage assessment of a target before striking, which will have the same number of missiles to strike a larger number of targets with the same assured probability of kill.

Both manned and unmanned aircraft in these future environments will need communications links in order to fight and operate as a network. U.S. satellites will be vulnerable to a range of kinetic and non-kinetic disruption. High-altitude long-endurance unmanned aircraft can operate as pseudo-satellites or pseudolites performing as redundant back-up layer to space.

The Air Force in fact has already proven this concept with two existing Global Hawk unmanned aircraft that have communications relays. Now, two aircraft is not sufficient to make an entire network of pseudolites. The Air Force has a plan to build such a network called the Joint Aerial Layer Network. And last year, it was reported that it was fighting for funding within the Air Force. Elements of JALN, as it is called, are funded within the Air Force, including communications links between existing manned aircraft but not an entire network of pseudolites.

U.S. surface ships face threats from enemy swarming small boats that could overwhelm from multiple directions at the same time. Unmanned surface vessels could be used to counter this threat

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by interdicting them from a distance away from U.S. ships. In 2012, the Navy tested the ability to launch a missile from an unmanned surface vessel demonstrating this concept.

Many countries around the world are developing unmanned surface vessels, including the U.S. Navy for counter-mine operations but not currently for ship defense. Similarly, swarms of low-cost drones could be used to attack U.S. ships or U.S. ground forces. The Navy is developing a low-cost-per-shot laser weapon and will test one at sea later this year. This would allow the ability to shoot down these drones at very low cost, not – much less expensive than using a missile.

Another method that has been proposed and which the Navy is currently researching are counter-swarms of low-cost expendable unmanned aircraft that could be launched from U.S. ships or ground bases. Now, this is a different paradigm for the U.S. Department of Defense that typically invests in large, exquisite and expensive multi-mission systems in very few numbers.

The U.S. Air Force recently launched a plan to investigate potential uses for small, unmanned aircraft, so when that plan is released, look to see whether or not it includes the concept of large numbers of expendable aircraft.

U.S. ground forces will face threats in the future from precision strike weapons in the hands of non-state actors. These include anti-tank guided missiles, guided rockets artillery and mortars and swarms of low-cost drones.

Ground robotic systems can help by being the vanguard of an advance. When making a movement to contact, it should be the robots making contact with the enemy that can flush out enemy forces and take risks that commanders would not be willing to take with man tanks or ground vehicles.

Most importantly, these can be built at very low cost, using existing platforms that are already in the U.S. inventory. The Army has thousands of Humvees and M113 armored personnel carriers that will not use in future conflicts because they are not survivable enough in this threat environment to have humans inside. But they would be survivable enough for robotic system because they could be built at low cost using robotic appliqué kits that apply sensors and autonomy to existing platforms, large numbers of them could be built. If they were lost in the battlefield, that would be acceptable. They would be expendable, replaceable, and no human lives would be lost.

The Army currently has medium altitude unmanned aircraft that it uses for reconnaissance close air support, for communications links. In the future, these aircraft will be increasingly autonomous allowing one person to control a swarm of unmanned aircraft. These could be used to cover ground forces as a self-healing mobile network, adjusting to bandwidth requirements and tasking of reconnaissance missions by ground forces.

Now, the Army has recently expressed interest in using robotic systems to offset what will inevitably be a smaller army in the future. The Army has heavily invested in small unmanned ground vehicles for bomb disposal and reconnaissance, as well as larger vehicles for reconnaissance – or, excuse me,

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for bomb disposal – and the Army is currently investigating appliqué kits for cargo vehicles to get soldiers off of roads.

But some of these concepts, like using ground vehicles for maneuver warfare, only exist on the drawing board and are not currently funded within the Army. These touch on core missions of the Army. So as the Army begins to flesh out its concept, we'll see whether it includes robotic systems in these roles.

Under sea is one of the few areas where the United States has tremendous advantages today. It can put a U.S. submarine right off the enemy's coast, launch Tomahawk land attack cruise missiles, and in the future even UAVs.

Unmanned systems can help sustain and press forward this advantage by tracking enemy submarines and ships. Undersea pods can be seated into a battle space ahead of time and, on order, launch unmanned vehicles or even unmanned aircraft that float to the surface and then launch.

This is another area, again, where commercial innovation is driving much of the technology. Oil and gas industries are heavily invested in autonomous undersea vehicles. And so this technology will be widely available to a range of actors. In order to stay ahead undersea, the U.S. military will need to invest aggressively in undersea vehicles. The Navy is moving on in this area but it also has not been immune to recent budget pressures.

Collectively, unmanned systems can be used in a wide range of missions across the battlefield in all domains and against a range of potential threats. Now, many of these concepts are not new. They are captured in various vision or roadmap documents throughout that have been released by the Department of Defense. Two in fact were released in just the last six months, a DOD wide road map that came out in December and an Air Force document articulating the future direction forward, or as the Air Force calls them remotely piloted aircraft.

Now, these documents represent what might be possible in the future with unmanned systems. But the most important document to be released by the U.S. Department of Defense in the last six months and what will lay out what actually is the plan for the future is the DOD budget. As I've alluded to in many of these examples, there's often a disconnect between what is in these vision documents and what is actually funded in the budget.

Now, all new programs, unmanned or not, face challenges inside the Department of Defense for funding. They need to fight an uphill battle for funding against existing programs and entrenched bureaucratic interests. But culture also plays a significant role in decisions about what gets funded and what does not. Money is tight at the Department of Defense, but what initiatives receive funding reflect choices by senior military and civilian leaders, and those choices are shaped by culture and bureaucracy.

To give one example, I want to talk about how the Army and the Air Force use their unmanned Aircraft differently. The Air Force has the MQ-1B Predator and the Army, the MQ-1C Great Eagle.

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Now, to a lay person, they would look undistinguishable. It's the Air Force one on top. They are built by the same contractor, based in the same underlying technology, but they implement that technology differently, and, most importantly, they are used very differently.

The Air Force uses officers to fly their unmanned aircraft. The Army uses enlisted personnel. In fact, it's not really appropriate to call the Army personnel pilots. They're controlling the aircraft. The aircraft in fact fly themselves, the Army aircraft. They take off and land on their own. They can fly point to point and the personnel controlling them directs them where to go.

Air Force aircraft, on the other hand, are flown by a pilot in a Mech cockpit on the ground with a stick and rudder. There are differences as well. The Air Force flies their aircraft remotely from the United States. The Army forward deploys their personnel. What this means is that for the Army, roughly, two people are needed for every one deployed so that they can rotate their personnel. They can't obviously keep them deployed indefinitely.

Now, what the Army could do is adopt a hybrid concept, where in addition to deploying out personnel, when they're back in the States and they're not performing other training or spending time with their families between deployments, they could support real world operations remotely. What this will enable the Army to do is provide additional combat power at very low cost, leveraging existing aircraft and people that it already has in the force. Moreover, this would help those pilots or controllers, as they are, maintain currency and they could, in fact, even maybe support operations in the area they're going to deploy.

But the Army has not embraced this concept. What the Army is doing is they're moving out on multi-aircraft control and will field a ground control station next year that has the ability to allow one person to control two aircraft at the same time. This is possible because of the high degree of automation in their aircraft. This is a baby step towards swarming in a future, where one person will control many vehicles.

The Air Force, on the other hand, sees multi-aircraft control as a decade after next technology. The Air Force experimented with early versions of multi-aircraft control and found the human-machine interfaces and the human task loading unsatisfactory and overwhelming for pilots, again, less automated in their aircraft. Now, in 2010, Secretary Gates directed the Air Force to develop improved multi-aircraft control to overcome these concerns and improve the technology. And he included the funding to do so in the DOD budget but it has not been developed.

Culture shapes choices about how militaries look at new technologies and what uses are perceived to be appropriate or not useful. Examples about throughout military history: elements of the Navy initially resisted the transition from sail to steam powered ships; parts of the Army resisted the transition from horses to tanks – it was the cavalry – and perhaps, most infamously, the Army went so far as to court-martial early air power advocate Billy Mitchell. In some cases, these choices are implicit and where service priorities lie for investment. In other cases, they are quite explicit.

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Casualty evacuation seems like an area that will be ripe for unmanned vehicles. Almost by definition, casualties are likely to occur in dangerous areas. Unmanned vehicles could be built at low cost and seeded forward into the battle space to shorten the time from point of injury to when those casualties reach a higher standard of care, which is critical in improving their odds of surviving. In fact, the military has already invested in unmanned cargo aircraft and is purchasing more, like the K-MAX helicopter that is currently deployed in Afghanistan, and there may be situations where this could be used to carry wounded personnel back when there are no other alternative. But not only is the military not investing in modifications necessary to make those possible and safe to transport casualties, but the Army actually has an explicitly policy against it.

Now, there are concerns with placing wounded personnel aboard unmanned vehicles. These include safety and continuity of care. But a comprehensive three-year NATO study that included U.S. service members looked at these concerns and ultimately concluded that there were some situations where placing a wounded person aboard an unmanned vehicle would not be appropriate but that there are others where that may be the only way to save that person's life and a blanket prohibition did not make sense. Nevertheless, the Army has reinforced its policy with not one, not two but three memorandums, the most recent one released this spring.

Now, I want to be clear. I am not suggesting that militaries as a whole are resistant to innovation. Sometimes that's a caricature that's made of militaries. I don't believe that the history of adoption of unmanned systems supports that, nor do I believe, based on my personal experiences in uniform in the Army or the five years I spent working these issues as a civilian in the Pentagon that that's the case. What is true is that change for all of us is hard when it impacts our core identity.

When the Navy transitioned from sail to steam, what was at stake was not a new technology but the essence of what it meant to be a sailor. Well, being a sailor no longer meant climbing the mast and working the rigging but now working down in an engine room, being an engineer. And, of course, as we know in our daily lives, new technology often does not work well at first. One empatizes with the U.S. Army cavalrymen of the inter-war period who looked at horses that had been used reliably by militaries for thousands of years and looked at the tank, which was arguably a new and unproven technology. Of course, if the U.S. Army had not adopted tanks, the history of the 20th century might have been very different.

These issues are explored in our new report, Robotics in the "Battlefield Part One: Range, Persistence and Daring." It includes key recommendations for action for the U.S. Department of Defense that takes positive steps forward in these areas, including incremental technology development and experimentation to overcome some of these concerns. Culture and bureaucracy cannot be swept aside but they must be addressed to the ability to build trust with new technologies over time and improve those technologies.

Innovation is a core theme of the U.S. QDR, but support for innovative ideas is needed if those sentiments are to be anything more than words on a paper. That includes funding. And, again, the issue is the balance of investments across the department's portfolio, one out of every $20 currently spent. But it also includes support for some of these challenging concepts of operation.

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The 20YY Warfare Initiative will examine these and other new concepts of operation that robotics might bring to the battlefield. "Robotics in the Battlefield Part Two" will be released this fall and will examine swarming and the ability for large numbers of robotic systems that are networked and cooperative to bring game-changing effects in the battlefield. We will also continue to more closely examine cost associated with unmanned systems, where they may cost more and where they may cost less than equivalent manned systems.

The emerging robotics warfare regime also raises challenging policy and strategy questions, many of which are not in a distant future. Just last year, China flew a drone into contested airspace in the East China Sea. And, in response, Japan scrambled an F-15 fighter. Now, if one country shoots out another country's drone, is that an act of war? Perhaps most troubling: would a country be more willing to shoot one down because there no humans on board? And, in fact, would countries be more willing to place a drone in harm's way in the first place because they're not risking anyone? There are no easy answers to these questions but policymakers should consider them before the heat of a crisis.

Closer to home, unmanned systems raise challenging questions about the use of force and war powers. Does the War Powers Resolution apply to unmanned systems? In Libya, the Obama administration asserted it did not. Now, there are arguments on either side of this debate but the key thing is that if unmanned systems are going to be used in a wide variety of roles in the future, then the implications of that decision are quite profound.

The 20YY Warfare Initiative will explore these and other areas, including ethical autonomy, the balance of human and machine decision making in many areas, particularly in the use of force.

The robotics revolution is coming. It will be driven by innovation in the commercial sector and the stakes in understanding this emerging warfare regime are high. Military history is littered with examples of militaries that fail to adapt to new technologies and lost battled or even wars as a result. It is important for any military that wants to stay head to be able to adapt to this technology, and, in particular, the new concepts that it unlocks. The winner of the robotics revolution will not be who develops the technology first or even the best technology but who comes up with the best ways of using it. Thank you. (Applause.)

Okay. I think we have a couple of minutes for questions. And there should be someone running around with microphones. Yes. And please introduce yourself.

Q: Charlie Dunlap from Duke Law School. Paul, you seem to be very confident that the data link that is necessary would be robust enough against a first world adversary. Are you sure that that's going to be true?

And then the second question, you know, the world has turned against autonomous weapons systems. That's why we have the Ottawa Convention. And why do you think that the world is going to embrace a system – any networked system is going to have to have a fully autonomous mode, I

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believe, because I don't think the data link can be reliably, you know, kept in place over the course of any contested environment. Why do you think that the world will suddenly turn around? It's not a matter of – so much a matter of ethics, but a matter of law and what the world community seems to want?

MR. SCHARRE: Thanks. You hit on really one of the core vulnerabilities of unmanned systems. The main limitation in taking a person out of some kind of vehicle is, of course, you lose the cognitive abilities of that person. And so they're replaced by some mixture of autonomy and then your communications links back to some human controller.

Currently, our aircraft are entirely vulnerable to really what are quite fragile communications links. They require a high amount of bandwidth, and if you cut those communications links, the aircraft would have – are not very smart, if you will. They can, you know, fly in an orbit or to a particular point in space. More sophisticated ones, like the Global Hawk, can go fly to a place and land.

There's a lengthy section in the report that talks about this but it's really a mixture of increased autonomy and getting the bandwidth requirements down. So the bandwidth requirements for command and control of the aircraft are actually relatively limited. The bulk of the bandwidth as needed for today, we're streaming high-definition, full motion video back. That requires a tremendous amount of bandwidth. Command and control for the vehicle is actually about an order of magnitude less than that.

So if you can do additional data processing onboard or if you can come up with methods where you don't need to actually stream back full motion video – so, let's say for example, in this scenario, we have a vehicle hunting mobile missile launchers, you don't really need to see every single image. What you need to see is if you can build an onboard processing that's good enough to queue you to what might be a mobile missile, then you send back a picture of that, and a surrounding area and the geolocation coordinates back to a human controller. So you can reduce those bandwidth requirements significantly.

There's cost associated with that. You know, one of the key things in staying ahead in this area is going to be the ability to pull in commercial sector innovation. And so, you know, you want a paradigm where you're able to rapidly update both your hardware and software to leverage the technological – you know, basically the computer processing power that is continually advancing. You don't want to have build – some of the software, you've got to do yourself, but you don't want to have to do all of that on your own, and you don't want to be 10 years behind the power curve.

To your other question about autonomy, this is something we're going to continue to explore. This was recently discussed at the U.N. Convention on Certain Conventional Weapons in Geneva last month. There's a campaign to ban killer robots, not define exactly what that is but it seems really frightening and a bad idea. Concerns, there's certainly more ethical concerns. There are safety, there are – (inaudible) – war concerns. I think the right model is that you have machines doing things that you can trust a machine to do, navigation, maybe queuing a person to a target but people

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are making the decisions that people must make, and, in particular, selection of particular targets for the use of force.

There's another question. Yes, sir.

Q: I'm Doug Samuelson from Group W Consulting, an R&D firm here in the area. How much have you thought about the other resources that go into operating and maintaining UAVs? You've got training. You've got maintenance. You've got software. You've got retrieval because, even though in theory you may never care about retrieving them, and practice in many cases you do, any thoughts?

MR. SCHARRE: Yeah. I mean, all of the history of innovation in warfare suggests that it's not really about the technology. It's about how militaries decide to use the technology, whether they incorporate the right training, the right organizational structures to adapt. There are many examples of scenarios where you have militaries that, you know, had some element of the technology but really never sort of figured out how to change their concepts of operations.

So that's ultimately really the core issue behind it. If you maybe have the widget but you're using it the wrong way or even train people appropriately, it's not ultimately going to be successful.

Yeah. Yes, sir.

Q: Hello. I'm John Hanley (sp). I was a former submariner, and we used to be pretty autonomous in the old days.

MR. SCHARRE: Yes.

Q: And when we were operating anywhere near our forces, we had lots of problems with blue-on-blue attack. We knew where we were. Our submarine operating authority knew where we were, but the rest of the force didn't. And then you get into a coalition environment, where you've got water space management issues, where you've got lots of other forces with submarines – countries with submarines out there.

Have you thought through the command and control not of just controlling, you know, multiple aircraft, but force command and control, and particularly in a coalition environment, where you have, you know, many nations that are either allies or don't have the same air picture, et cetera, et cetera?

MR. SCHARRE: No. I think that's a great question. So, yeah, there are sort of two components to that. One is as you start to have lots of vehicles – and today, the technology is really people have done, you know, a handful of small single-digit numbers of vehicles operating together, sometimes across multiple domains so maybe air and ground vehicles together – (inaudible) – to increase what's the human command and control paradigm, how you control a swarm; what does that mean; what does that look like? That's something we're going to continue to explore.

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Your question, the other part, mostly just about interoperability – one of the things people are working very hard on is even among our own vehicles that exist today, they're not interoperable. They have different communications links. They have different sensors. They have different control mechanisms. The services are moving out at least for ourselves to ensure that we have common control mechanisms so that if you give something to a solider/Marine on the ground, you give them one thing, not like 10 different tablets they've got to control. And, similarly, they're experimenting with sort of common ground control station architecture for unmanned aircraft.

Now, the plus side is if we can get towards a place – and this is challenging today – where you can export some of these technologies, then if allies and partners are using what we have, then that solves some of that problem. There are training aspects and doctrine aspects. If you get to the place where you say, this is ours and nobody can have it, even if you're a close ally and everyone's building their own, that's really going to be an uphill struggle.

Yeah. Yes. Someone way in the back. I don't know if we've got a microphone near you. Thank you.

Q: Eric Larson (sp), currently on the Joint Staff as an Air Force officer. Two questions: how does the Google car play into all of this? And then, also, how did generational differences in how my generation, previous generations and future generations, how comfortable will we be with some of the new technology on the battlefield? I mean, there's the Google car in the general population but then the specific generational differences.

MR. SCHARRE: Sure. So on the Google car, first of all, it's an interesting example. On the one hand, here's a technology that you could see importing in many ways from the commercial sector.

You know, I think when you think about how to have a military that is positioned to take advantage of these adaptations, you want to think about different types of investment, what are areas that you can draw in what's already being made with some modifications, what are areas where you take the underlying technology that maybe enables it, but you have to build things your own.

So, for example, the Navy landed an aircraft on an aircraft carrier. That landing mechanism, you're not going to buy off the shelf somewhere. You have to build that. And where are things that really the fundamental research is going to have to be done by the department, things like directed energy weapons, laser weapons.

One of the – so when you think about this, you say, all right. Maybe we could just buy a self-driving car. We don't have to build our own. Now, in fact, what Google has done is they've used LIDAR, it's like a laser sensing mechanism to basically map the area around Google, the Silicon Valley environment to a high degree of fidelity, down to allegedly line one centimeter, you know, in curve and things like this. Now, that's obviously overseas, you're not going to have that luxury. And so that's a huge difference. And so there are limitations when you take – actually the story – the sort of term for this is the kidnapped robot problem. So you have this robot and it's operating in this

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environment that you've mapped out but if you take it and put it in some new place, it's just – it's hopeless sometimes.

So there are maybe places where, you know, there needs to be some new investment, you know, GPS for the environments we're going to be operating in, maybe not reliable.

In terms of generational challenges, there are probably issues certainly about trust for autonomy. One of the interesting things that's come out in research about how a person controls a swarm of autonomous agents, and, in many cases, this is done digitally right now through simulations, is that personality preferences matter a lot.

So what you ideally want is you want someone that understands the problem, the environment that you're operating in, and they understand the algorithms that the agents are running, and then when they will succeed and solve the problem optimally and when they might fail and a person has to intervene, well, that requires, you know, understanding the environment, of course, understanding the technology, but also, of course, like sort of the appropriate level of trust. And so that's a nascent area because you don't want someone that is overly trusting and they sit back, and then the machine fails, and they don't do anything. And you don't want someone that intervenes too much and then they lead to a suboptimal solution.

So I think there's probably a lot of potential there where people are just more comfortable with new technology, but there are probably also like interesting areas to better understand what exactly is the right skill set to perform those kind of jobs.

I think we have time for one more question. Yes.

Q: Jess – (off mic) – International and also the SDM MIT graduate program. Just a couple of things and I just want your opinion on them. I notice a lot of people use interchangeably unmanned versus autonomous but autonomous is autonomous and not unmanned. And two major characteristics of autonomous that I notice is, right now, it's okay to have an autonomous swarm if they're all identical siblings, if you know what I mean. In other words, they all have the same knowledge base. It's like, hello, my name is Albert; hello, my name is Albert; hello, my – you know. And the other thing is obstacles. I don't know, your opinion?

MR. SCHARRE: Good question. So just on terminology, so you have unmanned systems, which, of course, is not on the platform or on whatever the object is. Those could be remotely controlled. They could be autonomous. They could be semi-autonomous. Robotic systems have both attributes. There's not a person on board and then they have some level of autonomy. You can, of course, also have automated functions on vehicles that have people onboard. So the Air Force has something called the automated ground collision avoidance on some of their aircraft. Or if a pilot is about to engage in controlled flight into terrain, the aircraft takes over and flies at the last possible minute.

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In terms of swarming behavior, what's really interesting is when you look at sort of nature for examples where you have simple rules with things like ants and bees and termites that can have these really intelligence looking emergent behaviors that come out of them, a colony acting very intelligent. They can exhibit very intelligent sort of behaviors in terms of finding new nests or hives rather for bees, building objects for termites foraging for food. Those are all homogenous groups.

One of the things that you could do with a robotic system is – because it would be heterogeneous and you have a different mix – there's – and this is very new. There are some groups that have started work on this. There's one called – an organization built something called a swarmanoid. It's like it's got a swarm of robots, and there's like hand robots, and flying eye robots, and leg robots, and they come together to build some sort of creature that does things. It's kind of interesting, very nascent from a research perspective. Your second question? I'm sorry.

Q: The other thing is that there are still obstacles –

MR. SCHARRE: Oh, obstacles. Yes. So when it comes to – so undersea vehicles or aircraft, this is obviously much, much easier. In the ground domain, autonomy in terms of navigation is still really lagging behind. Again, Google is able to do what they're doing because they're mapping the environment. Negative obstacles, so just potholes, is really a problem for unmanned vehicles to identify that. So, you know, the DARPA Grant Challenge, where vehicles navigate across the desert, was several years ago now, but it's still a challenge to do – particularly if you imagine robotic vehicles moving through forests and there are many obstacles and they might get entangled. So it's something that's going to require a lot of work.

There may be opportunities there to like sort of combine those concepts so you have maybe like an air vehicle overhead that's launched from a ground robot that's providing another set of eyes. And people are working on early stages of cooperative air and ground vehicles working together.

Okay. I think we've got to go. All right. Thank you very much. I appreciate it.

(Applause)

(END)