研究会記録

Technological Revolutions in War:

From the Onset of the Industrial Age to the 21st Century

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The technology-driven revolutions of the industrial-technological age have been the defining developments of modernity. Over the past two centuries, innovation in technology accelerated dramatically in comparison to pre-industrial times, with military technology constituting merely one aspect of a general trend.

In pre-modern times, too, technology mattered, and some innovations in military technology profoundly affected warfare, and history in general, as we have heard. And yet, technology improved slowly in the pre-modern era. By contrast, from the beginning of the industrial-technological era, as military theorist J. F. C. Fuller saw, the pace of technological innovation became such that the best armed force of one generation would have been totally unable to confront in the open a well-equipped opponent of the following generation.

As Fuller equally saw, the advances in military technology were closely related to civilian developments; and both did not take place more or less evenly across the technological front, but clustered around consecutive breakthroughs in a number of particular sectors each time. [1] Fuller identified three such major revolutionary technological waves during the nineteenth and twentieth centuries, with which we are familiar as the First, Second and Third industrial revolutions, the last of this is also known as the electronics or information revolution, through which we live today.

The so-called First Industrial Revolution centered on the steam engine and on major advances in metallurgy and machine tools. The steam engine was applied to propel all sorts of different machines, revolutionizing one field of human activity after another. Originally developed to pump out water from mines, it was then harnessed to the newly-

[1] These ideas repeatedly occur in J. F. C. Fuller's voluminous writings; but see esp. his *On Future Warfare*, London: Praed, 1928; id., *Armament and History*, London: Eyre, 1946.

developed machines of the cotton industry. Applied to pull trains of wheeled carriages that ran on railroads, it revolutionized land transportation, placing it for the first time on equal footing with water transportation and opening up the interior of the world's great continental landmasses. And harnessed to a paddlewheel and then a propeller, it finally displaced the great sailing ships, one of the pinnacles of pre-mechanized technology.

The above changes affected the military field as deeply as they did civilian life. The railway increased armies' strategic mobility and logistical capability by a factor of hundreds. While naval mobility only doubled or tripled as steam replaced sail, naval tonnage grew 4-5 fold and battleship's size - and might - 10 fold and more.[2] To these was added the revolution in information communication, as electric telegraph lines connected not only armies across countries but naval bases across oceans and continents on real time, where weeks, months, and years had been necessary for the information to arrive.

Simultaneously during the nineteenth century, the revolution in metallurgy and machine tools generated a revolution in firepower and tactics. Rifling and breech-loading were pioneered in infantry firearms during the 1840s, and in artillery during the '50s and '60s. Magazine-fed rifles, 'repeaters', were developed in the 1860s and '70s, and quick-firing artillery in the 1880s and '90s. In consequence, range, accuracy, and rapidity of fire each increased some tenfold within sixty years, not counting the development of the automatic machinegun from the 1880s, which multiplied firepower yet more.[3]

All these, however, were lopsided revolutions, especially on land. As in the economy so in the military, spheres of activity to which the steam engine could not be applied remained manual and unaffected by the Revolution. Thus, while armies rode trains on their way to the battlefield and were easily controlled by telegraph, they fell from the pinnacle of high-tech communications back to Napoleonic if not Alexandrian times once on the battlefield. Their campaign and tactical mobility remained confined to human muscles, with their artillery and supply drawn by horses. Field command and control was similarly downgraded to messengers on foot or horseback. Furthermore, whereas firepower increased tenfold and more, troops, while dispersing and taking cover,

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[2] Data for Britain. See Quincy Wright, *A Study of War*, Chicago: U. of Chicago, 1965, 670-1 (military); and B. R. Mitchell, *International Historical Statistics, Europe 1750-1988*, New York: Stockton, 1992, tables F4 (merchant)

[3] Of the many references to these developments, Dennis Showalter, *Rifles and Railroads: Soldiers, Technology and the Unification of Germany*, Hamden, Conn.: Archon, 1975, and Daniel Headrick, *The Tools of Empire: Technology and European Imperialism in the Nineteenth Century*, New York: Oxford UP, 1981, are the most expert.

still had nothing better than their skin to protect them from the storm of steel on the open field. Hence the murderous stalemate on the Western Front during World War I, both tactical and operational. Even those puny gains made by attacking infantry at a terrific cost were reversed as decimated foot-walking troops, struggling to extend their tactical gains deeper, were pushed back by enemy reinforcements rushed up by rail.

However, from the 1880s onward a new revolutionary wave of industrial technology, the so-called Second Industrial Revolution, was beginning to unravel in civilian life, affecting the military field as profoundly as the First Industrial Revolution had. Chemicals, electric power, and the internal combustion engine dominated that second revolutionary wave. While the chemical industry contributed high explosives, and was soon to produce chemical warfare, and while developments in electricity also had various military applications, it was the internal combustion engine that affected war the most decisively. Lighter and more flexible than the steam engine, it made possible mobility in the open country, away from railways. Passenger and transport automobiles (as well as the tractor) rapidly evolved between 1895 and 1905, increasing cross-country mobility ten times. World War I inaugurated the tank – an armored and armed tractor – which introduced mechanized mobility and mechanized armored protection into the battlefield. Controlled by radio, which similarly extended real-time information communication into the open field, away form stationary telegraph lines, mechanized armies on tracks and wheels matured by World War II.

Simultaneously, the internal combustion engine also made possible mechanized air flight. A remarkably similar trajectory followed, with the first such flight taking place in 1903, and massive air forces quickly coming into being during World War I and further developing by World War II. At sea, dual propulsion by the internal combustion and electric engines made possible the first workable submarine in 1900, while the aircraft was to bring about the demise of the gunned battleship.

As all these developments matured by World War II, new technological breakthroughs were beginning to make their mark, most notably electronics, again revolutionizing both civilian life and war in the so-called Third Industrial, electronics, or information Revolution, which continues to unfold to this day. Radar, developed in the late 1930s, deeply affected air and sea warfare. From around 1970, electro-optic, television, and laser guidance for missile weapon systems began to revolutionize air-land and land battle. Since then, sensors of all sorts have been rapidly improving, in connection with the fast miniaturizing microchip that has doubled electronic computation capacity every eighteen months. As a result, the identification, acquisition, and destruction of most hardware targets have become almost a foregone conclusion, nearly irrespective of range. Showing little signs of levelling off, the electronic revolution is bringing about increasing automation and robotic warfare.

Consequently, the mechanized armies of the previous era have been shrinking in size and transformed to embrace electronic warfare themselves, offensively and defensively. The two Gulf wars demonstrated this most strikingly, for the Iraqi side that lacked the new technologies found out to its cost that its numerous old-style formations were as vulnerable as herds of prehistoric mammoths. The gap between developed and less developed protagonists seems to have widened considerably. And yet the latter have been adjusting quicker and in ways different than expected.

In the first place, less developed players have been moving to get rid of their heavy formations, adopting low-signature troops, weapons, and tactics. They aim to slip under the threshold of the electronic weapon systems, which are much better in identifying hardware than people. Second, the massive market penetration of new technologies into every aspect of daily life makes them available to less developed players as well, if not in the form of the most expensive cutting-edge systems then as widely-available and cheep gadgets. Satellite navigation systems that offer precision guidance, computer networks that can be exploited and disrupted, cellular phones that can be activated from afar, and cheap drones that can penetrate and attack - are some examples. Indeed, high-tech technologies have both polarized and democratized the balance between the more and less advanced sides in war, for the means to generate massive damage with pin-point accuracy have been trickling down to below the state level, becoming available to non-state actors as well.

We now move from the survey of history to discuss some general and recurring features of military-technological revolutions:

I begin with *Force multipliers, one-sided battlefield outcomes, and cancelling-out effects.*

With arms races gaining a wholly new significance in the technological age, swift changes in the balance of power due to innovation have become very much the rule. Particularly when one side succeeds in securing a decisive lead in the acquisition and assimilation of breakthrough weapon systems, it might gain a 'force multiplier' that can produce one-sided battlefield results. Over time, however, there would be a canceling-out effect, as rivals catch up in the development of new weapon systems and operational doctrines, and adopt countermeasures. Breach-loaders responded to breach-loaders; mechanized forces and anti-tank weapons countered mechanized forces; electronic disruption and suppression devices target electronic weapon systems.

Technology could also be transferred – sold or given – which occasionally narrowed the gap between more and less advanced rivals. Finally, extreme technological asymmetry has been countered by asymmetrical strategy. The Battle of Omdurman in the Sudan, where Kitchener's British army, employing machine-guns and magazine-fed rifles, annihilated the Dervish army, killing 11,000 at the price of 140 British casualties, demonstrated the huge gap that had been opening between technologically advanced powers and less developed rivals. Thereafter, the latter tended to avoid direct fighting, opting for guerrilla and other methods of irregular warfare.

A second point is the supposed *growing lethality of warfare.*

Weapon systems' effectiveness probably increased at about the same rate as productivity in general during the industrial-technological age: that is, by a factor of hundreds. But what exactly does this increase signify? Destructiveness or lethality may appear to be the issue, for that is what war is all about. However, no less than offensive capability, developments in military technology also exponentially increased protective power for example, through mechanized defensive armor at sea and on land, through growing, indeed, sometimes literally rocketing, swiftness and agility, and through electronic counter-warfare. Contrary to widespread assumptions, studies of war lethality show no significant increase during the nineteenth and twentieth centuries, relative to population.[4] Furthermore, the vast majority of the non-combatants killed by Germany during World War II, the most severe modern war – Jews, Soviet prisoners of war, Polish and Soviet civilians – fell victims to intentional starvation, disease, and mass executions, rather than to any sophisticated military technology. Indeed, instances of genocide in

[4] The general trend is more or less agreed upon by statistical studies such as: Melvin Small and David Singer, *Resort to Arms: International and Civil Wars, 1816-1980*, Beverly Hills: SAGE, 1982; Jack Levy, *War in the Modern Great Power System, 1495-1975*, Lexington: UP of Kentucky, 1983; Evan Luard, *War in International Society*, London: Tauris, 1986. Niall Ferguson, *The Cash Nexus: Money and Power in the Modern World, 1700-2000*, New York: Basic Books, 2001, 33-6, makes the point for spiraling lethality, but he scarcely controls for population (also as a function of the geographical scope of wars) and mobilization levels, and appears to be unaware of the heightened protective aspect of improved military technology.

general during the twentieth century, as earlier in history, were carried out with the simplest of technologies, with Rwanda being a chilling recent example.

A third point: not only the lethality but also the cost of *warfare is widely and wrongly supposed to have spiralled.*

The steadily growing cost of hardware in military spending has been a general characteristic of the industrial-technological age. However, again contrary to a widely-held view, weapon systems' cost, like military spending in general, did not spiral with every new generation, nor did they become prohibitively expensive. In fact, the peacetime military spending of the powers during the industrial age has remained remarkably stable, at less than 5 percent of GDP. That was the level of peacetime military spending among the European great powers in the nineteenth century,[5] and it remained surprisingly resilient during the twentieth century: over 5 percent of GDP for the United States during the Cold War; around 3 percent for the European countries. It has fallen much lower since the end of the Cold War. Thus, military spending did not 'spiral', but generally kept in line with the overall growth in GDP. Only in wartime, most notably during the two world wars, did the military spending of the warring powers leap to around half of their total GDP.

What is true, however, is that hardware's share of military spending, in relation to manpower, has grown during the industrial-technological era, with the rising cost of some weapon systems compensated for by smaller numbers or by a changing balance within military procurement, both matters of cost-effectiveness.[6] The problems of priorities that the American defense authorities are facing today with such expensive weapon systems as the air-superiority F-22 Raptor are not new.

The fundamental challenge posed by military-technological revolutions is that they involve a sweeping change that goes far beyond existing experience. The contours of the change are shrouded in the mists of the future, and can only be more or less successfully predicted. Nonetheless, huge investments in hardware and far-reaching adjustments to military structure and operational doctrine, which can only be tested in battle, are called for in the present. Of course, civilian firms, states, and individuals are also required to make decisions on future actions based on predictions. Still, the military

[5] David Stevenson, *Armament and the Coming of War: Europe, 1904-1914*, Oxford: Oxford UP, 1996.
[6] Cf. Ferguson, *The Cash Nexus, 30-33*; although I differ with some of his views here, our general conclusion is similar.

sphere is special in that the practical experience of war is not continuous but is limited to relatively short spates of active belligerency, separated by long periods of peace. Although armed forces attempt to overcome these gaps by means of operational analyses, simulations, and exercises, a continuous reality-check for the military does not exist in the same way that it does, say, in economic life. The long interruptions in the experience of war is the reason why armed forces are proverbially inclined to prepare for the last, rather than the next, war.

Furthermore, the problem in coping with technological revolutions is not so much to realize that such a revolution is in fact occurring, but to work out its exact form and practical implications. God or the devil are in the details. There were many early car manufacturers, but only Henry Ford got it exactly right, at least for a while. There have been thousands upon thousands of high-tech companies, but only the Microsofts, Apples, and Googles developed winning combinations.

During the 1930s, for example, contrary to mythology, the debate within the armed forces was not between far-sighted exponents of mechanization and their reactionary rivals, but revolved around far more concrete questions: should all tanks be concentrated in armored divisions, or should part of them be allocated to infantry support? And in connection with this, what types of tanks should be manufactured, and what would be the role of infantry and other traditional arms on the modern battlefield?[7] Conclusive answers to these questions were only given in the practical test of World War II.

This applied even more to air forces. Their major role in any future war was recognized by all between the World Wars, and it was in fact the radicals that proved mistaken in their most central assumptions. They believed that air forces were capable of easily and swiftly destroying the infrastructure of great powers and force them to capitulate. They thus claimed that armies and navies had only a secondary role to play, if they had not become wholly obsolete. At sea, it was not clear, for example, if the invention of sonar did not spell the end of the submarine, as Winston Churchill, for one, hoped. Nor was it known if the aircraft had rendered the battleship obsolete or would coexist with it. These critical questions were tested, and settled, only in World War II.

So far this paper has been confined to conventional warfare. But the most revolutionary technological breakthrough of the modern era has been the advent of

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[7] Azar Gat, "Ideology, National Policy, Technology and Strategic Doctrine between the World Wars," *Journal of Strategic Studies*, 24 (3), 2001, 1-18.

nuclear power and nuclear weapons. Here was finally the ultimate weapon that gives anybody who possesses the necessary stockpile the ability to completely destroy his enemy. This, however, means that when both sides possessed nuclear weapons their actual use in war has been deterred by the promise of mutually assured destruction. And yet this logic, which dominated the Cold War, may no longer apply as comprehensively as it did.

The change concerns not only nuclear but also biological weapons. The breakthroughs achieved in decoding the genome and genetic engineering have made the biotechnological sector into one of the spearheads of today's scientific revolution, together with electronics. As a result, biological weapons have become both much more lethal and accessible. A virulent laboratory-cultivated strain of bacteria or virus, let alone a 'superbug' with no immunological or medical antidote,[8] could make biological weapons as lethal as nuclear attacks, while being far more easily available than nuclear weapons.[9]

The root problem is the trickling down to below the state level of the technologies and materials of WMD. The ability of non-state actors to buy, steal, rob, or manufacture WMD has increased dramatically. Here lies the bewildering nature of the new mix which is unconventional terror. It is difficult to deter zealots who are willing to sacrifice their lives and may positively desire a general apocalypse, and who, in addition, are too elusive to offer a clear enough target for retaliation. For this reason the use of ultimate weapons is *more* likely to come from them than it is from states. Unconventional capability acquired by terrorists is *useable*. Scenarios of world-threatening individuals and organizations, previously reserved to fiction of the James Bond genre, suddenly become real.

Hence the alarm raised as jihadist Islamist organizations win control over large territories. Recent years have seen the collapse of state authority in a number of countries in the developing world, most notably Syria and Iraq, Libya, Yemen, Somalia and north Nigeria. In all of them, militant Islamist organizations thrive. The rapid expansion of the Islamic State in Iraq and Syria (ISIS), coupled with the organization's virulent anti-modernist ideology and hideous practices, have attracted particular attention. Only last

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[8] Philip Cohen, "A Terrifying Power," *New Scientist*, Jan. 30, 1999, p. 10; Rachel Nowak, "Disaster in the Making," ibid., Jan. 13, 2001, pp. 4-5; Carina Dennis, "The Bugs of War," *Nature*, May 17, 2001, pp. 232-35.

[9] Spencer Hsu, "Modest Gains against Ever-Present Bioterrorism Threat," *Washington Post*, Aug. 3, 2008.

week we had a report on the capture in Moldova of radioactive material smuggled for sale in the Middle East and suitable for the preparation of a dirty bomb.

Thus, the greatest threat of nuclear and other forms of nonconventional weapons proliferation lies in the increased danger of either leakage or anarchy in the less developed parts of the world. Nuclear and unstable Pakistan demonstrates both dangers. The collapsed Soviet Union of the 1990s and the concerns regarding its nuclear arsenal and unemployed scientists, rather than the former nuclear superpower, may be the model for future threats. Although the world has become more peaceful than ever, especially in its most developed parts, there is no room for complacency, as the democratization and individualization of the technology of mass destruction present new and alarming challenges.

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