The unrecognised simplicities of effective action #2:
'Systems engineering' and 'systems management' — ideas from the Apollo programme for a 'systems politics'

'It may turn out that [the space program's] most valuable spin-off of all will be human rather than technological: better knowledge of how to plan, coordinate, and monitor the multitudinous and varied activities of the organizations required to accomplish great social undertakings.' Editorial in Science, November 1968.

*'There isn't one novel thought in all of how Berkshire [Hathaway] is run. It's all about … exploiting **unrecognized simplicities**… Warren [Buffett] and I aren't prodigies. We can't play chess blindfolded or be concert pianists. But the results are prodigious, because we have a temperamental advantage that more than compensates for a lack of IQ points.' Charlie Munger, Warren Buffett's partner.*

This blog is the second in a series (first one HERE). The overall focus is:

> How to 1) embed in 'mission critical' political institutions the unrecognised simplicities of effective action including personnel selection, education, training and incentives to improve dramatically, reliably, and quantifiably the quality of individual and institutional decisions and develop high performance man-machine teams, and 2) develop a *focused* project that radically improves the prospects for international political organisation to minimise effects of competing nation states and avoid massive disasters. The two are entangled.

This paper considers the development of new ideas about managing complex projects that were used by George Mueller to put men on the moon in 1969. These ideas were then applied in other mission critical teams and could be used to improve government performance. Urgently needed projects to lower the probability of catastrophes for humanity will benefit from considering why Mueller's approach was 1) so successful and 2) so *un*-influential in politics.

Core problem: mismatch between political institutions and the scale and speed of change

The government system (in the UK and most of the world) is a combination of, *inter alia*:

1) extreme centralisation of power among ministers, officials, and advisers almost none of whom are +3 standard deviations (~1:1,000) on even one relevant dimension (IQ, willpower/toughness, management ability, metacognition etc) because the selection, education, training, and incentives are screwed (NB. how the apex of the British state imploded on 23 June 2016 against a ~£10^7 information operation cobbled together by 10 people in 10 months);
2) extremely powerful bureaucracy (closed to outside people and ideas) defined by dysfunctional management incentivised to spew rules rather than solve problems (and no reverse ratchet);
3) most major elements of the system including political parties are incentivised to focus on trivia, not solve deep problems;
4) a media programmed largely to spread confusion combined with an intelligentsia that even (especially!) at the highest levels is dominated by a political culture of fairy tales and very little understanding about effective action (look at top scientists' attempts to combat Trump).

This is a *system* failure — the political system possesses few error-correcting features seen in markets and the scientific method so *it cannot fix itself*. Overall this system has visibly failed with 'normal' Government. Further the 'mission critical' elements of this system in the UK and across the world are very similar to those that failed so spectacularly in each Great Power in summer 1914: wrong people, wrong training, wrong management, wrong incentives so the same stories in every crisis (groupthink, confirmation bias, management chaos as events move faster than internal OODA loops, and so on).

These deeply flawed institutions confront a profound inflection point for humanity in the form of already existing WMD combined with accelerating technologies including genomics, gene editing, and machine intelligence. They *already* face crises moving at least ~10^3 times faster than July 1914 and involving ~10^6 times more destructive power able to kill ~10^{10} people (all of us). The depth of this mismatch between technological change and political institutions is growing every year. Change outpaces the ability of political institutions to adapt and the overall system spontaneously generates crises that can easily escalate into disasters — it does *not* tend towards 'equilibrium' as the flawed standard models of conventional economic theory assume (hence partly why their predictive power is so bad).

The *good news* is that we have discovered a lot about high performance teams (HPTs) stretching back thousands of years of recorded history and literature. The *bad news* is that our evolved nature makes it very hard to accept and apply these lessons and our political institutions are constructed in such a way as to make it practically impossible (and mostly illegal) for them to reach high performance. Even more difficult: HPTs are inherently dangerous and in many areas we must be wary of giving them centralised power. We need HPTs reliably at the apex of politics (very hard) that are compatible with Maddison's warning 'if men were angels no government would be necessary' (even harder, maybe impossible) and we also need *decentralised* systems to control far more aspects of life than they now do (bitterly resisted by the powerful government bureaucracies that control almost everything regardless of who wins elections).

Is there a way to make progress so that the probability of massive disaster significantly reduces and the probability of our adapting to big problems improves? If yes, then many problems will be solved automatically, though inevitably patchily, by the error-correcting institutions of science and markets. If no, then huge disasters become probable within decades because of the simple statistics of cumulative probability: e.g. a 1:30 annual probability becomes practically guaranteed within a century.

I discussed this core problem in the first blog but was not clear enough that one of the goals of this series of blogs is to produce *a programme for a cheap training course that could improve the performance of the top 10^2 decision-makers for less than £10^6.*

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This paper concerns a very interesting story combining politics, management, institutions, science and technology. When high technology projects passed a threshold of complexity post-1945 amid the extreme pressure of the early Cold War, new management ideas emerged. These ideas were particularly connected to the classified program to build the first Intercontinental Ballistic Missiles in the 1950s and successful ideas were transplanted into a failing NASA by George Mueller and others from 1963 leading to the successful moon landing in 1969.

These ideas were known as 'systems engineering' and 'systems management'. They proved extremely successful in certain domains. (The contrast between this success and the repeated failure of the joint European space project, ELDO, is also interesting.) These lessons have been transferred to 'mission critical' teams such as aircrew and military special forces. Recently some of the ideas were transferred to JSOC — the classified element of US special forces — and its intelligence activities. The consensus (including from UK special forces operatives) is that this was a striking success. I will return to some of these examples in a later blog. Despite initial hopes these ideas have very rarely been transferred into political projects and nowhere (I am aware of) on a large scale with clear success though some of what Singapore is doing seems to be based on similar principles. I will return to this in a later blog.

Part of the reason for making such an extreme effort to win the referendum was that victory would greatly improve the probability of enhancing the performance of core institutions of the UK state with great advantages not just for the UK but also Europe and the rest of the world. The process of leaving necessarily involves profound institutional and policy 'reboots' and therefore provides unusual chances to replace dysfunctional systems (e.g. from government procurement to budget processes and crisis management). There will be a desperate scramble for new ideas.

This usually happens in response to an event like 1929 or 9/11. The referendum is a similar scale event requiring huge changes despite opposition from almost all of the most powerful people who were happy with the status quo. There is almost no way for people outside a set of ~100 to influence such things much directly but Monnet showed that if ideas are developed in advance then sometimes they are grabbed by powerful people searching for a path in short-term crises. That approach built the EU so perhaps it can reverse it too.

The project of rewiring institutions and national priorities is *a 'systems' problem requiring a systems solution*. Could we develop a *systems politics* that applies the unrecognised simplicities of effective action? The tale of George Mueller will be useful for all those thinking about how to improve government performance dramatically, reliably, and quantifiably.

For those without the interest or the time for the history who want to go straight to possible 'lessons' and action, go to page 21 ('legacy and results', particularly from page 26). This section also compares Whitehall against Mueller's successful principles. *These principles are an almost exact anti-checklist for how Whitehall and almost all big organisations (private or public) work.* With each principle behind success one can say 'tick, this doesn't exist and/or is illegal in Whitehall'. It shows how hard improving things is but also the scale of improvement possible.

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From ICBMs to the moon: the emergence of **systems engineering and systems management**

Two weeks before the successful launch of Apollo to the moon in 1969, the F-8 rocket assembled by the European Launcher Development Organisation (ELDO) failed on the launch pad. This was the latest in a string of failures over years. The difference between NASA's success and ELDO's failure was one of *management*. For NASA's success 'a managerial effort, no less prodigious than the technological one, was required' (Seamans & Ordway).

The Apollo program would eventually employ 300,000 individuals working for 20,000 contractors and 200 universities in 80 countries, at a cost of about $19 billion. Organising the integration of millions of things and many complex processes to produce a new vehicle that could take man to the moon and return him safely to earth was a very different problem than basic science research, normal engineering, or normal management. New ideas were needed.

In 1963, George Mueller came to NASA to build a new management system. NASA was wracked with internal conflicts, divisions between different groups and different physical locations, a lack of operational and managements skills, and political problems. Mueller instituted **'systems engineering' and 'systems management'**. The concepts of 'systems engineering' and 'systems management' developed in America in the 1950s during the development of the classified ballistic missile programme and attempts to automate air defence (the SAGE project). Both were central to the strategic and technological challenges of the Cold War as both sides developed nuclear weapons and experimented with missiles. Both programmes involved unprecedented technical and management challenges.

Some pre-history

1900: The birth of 'scientific management' and Frederick Winslow Taylor

The 'scientific management' revolution was introduced by Frederick Winslow Taylor in the early 20th Century. It was undoubtedly successful in certain domains. I will not go into it in any detail but it is useful to have a very crude sketch in mind as backstory for systems management.

At the 1900 Paris *Exposition Universelle*, Taylor demonstrated that he could make more steel, faster, and cheaper than anybody else. His demonstration mirrored part of his US factory and showed he could cut about five times more steel per minute than normal. The secret was not a breakthrough technology but a breakthrough management process. He paid extreme attention to the details of each aspect of the manufacturing process and experimented to optimise each part.

He had attended the Phillips Exeter Academy, the closest America equivalent to Eton (where the likes of Gore Vidal went). He turned down Harvard to take a job in a factory which he later called 'the most valuable part of my education'. He saw how everybody did things differently with no thought for what was most efficient. Initially workers resisted his attempts to tighten processes. He then decided to *show them*. He prowled the floor with a stopwatch, pen, and ledger. He broke down all the parts, measured them, and did experiments. Many workers saw it as humiliating and tried to rally support against being timed with a stopwatch. Their attempts to strike were undermined by his growing knowledge.

What had been skilled jobs relying on judgement became less skilled jobs performing simple repetitive tasks. He could let them go and hire new less skilled people. His approach brought gains from specialisation as per Adam Smith and David Ricardo. It depended on a rigid hierarchy in which those at the bottom were told not to think but to execute simple tasks in the exact way stipulated.

He called it *'scientific management'*. He told workers, 'I have you for your strength and mechanical ability. We have other men paid for thinking.'

Taylor's ideas spread. Henry Ford's production line introduced in 1913 was a natural extension of Taylor's ideas and compressed the production of a car from days to about ninety minutes. By World War II, America could take millions of people from agricultural jobs and get them churning out aircraft carriers on a scale that nobody could compete with.

Taylor was convinced that his principles could be extended throughout society and he was extremely influential.

> 'The same principles [of scientific management] can be applied with equal force to all social activities: to the management of our homes; the management of our farms; the management of the business of our tradesmen, large and small; of our churches, our philanthropic institutions, our universities, and our government departments.' FWT

While his approach works for certain sorts of relatively simple operation *it cannot be extended to relatively complex operations*.[1]

Operations Research migrates from Britain to America

In 1936, Tizard worked on integrating the new technology of radar into Britain's air defence system. Machines, operators, and institutions - makers and users, men and machines - had to work together in an environment of unprecedented technical and organisational complexity. He worked with the RAF on a series of experiments at Biggin Hill. Researchers were differentiated between those working purely on the technology, known as 'developmental research', and those working on the operational issues which became known as 'operational research' (OR). Crucially, the skills of both types were grounded in maths (pure and applied), physics, and engineering. The central point was to have *people with quantitative problem-solving skills examining operational and institutional problems* - not just the technology problems. The RAF maintained a group of scientists and engineers to advise on the use of the air defence system. After the Battle of Britain in which radar was critical the tools of OR spread to other problems such as strategic bombing and how to combat U-boats in the Battle of the Atlantic.

Initially Vannevar Bush, the very influential head of the National Defense Research Committee (NDRC) and Office of Scientific Research and Development (OSRD), resisted the spread of OR. After Pearl Harbor the US military realised it was badly prepared. Despite Bush's resistance British ideas on OR began to be imported into three areas in particular: air defence, anti-submarine warfare, and strategic bombing. Warren Weaver, chief of the NDRC's Applied Mathematics Panel (AMP), came across OR when in Britain in 1941 and promoted it despite Bush. Weaver also paid von Neumann (see below) to work on applied problems for AMP. A group was established under the MIT physicist Philip Morse to use OR for anti-submarine warfare (ASWORG) and Bowles in the War Department pushed OR. Bush eventually yielded to pressure and events. In 1943 the OSRD established the Office of Field Services (OFS) and all branches of the military rushed to set up their own teams. It had many successes, most famously the operation (ALSOS) at the end of the war that hoovered up Nazi technological secrets including its atomic programme. OR, often known in America as Operations Analysis (OA), helped integrate thinking across existing institutional boundaries. This was fruitful and naturally problematic.[2]

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[1] Cf. Chapter 2 of *Team of Teams*, McChrystal.

[2] Cf. *The adoption of operations research in the United States during World War II*, Rau.

'Systems' thinking emerges with the gunfire control prediction problem in World War II

A systems approach emerged in wartime work on problems of gunfire control. Institutions like Bell Labs and MIT's Radiation Laboratory and people like Ivan Getting (MIT) tried to get *control engineering* on a sound theoretical basis. (It was natural for Bell Labs, a telephone company, to get involved in the fire control prediction problem because there are close analogies between it and problems in communication engineering.) During WW2 teams had to combine radar and gun control into an automated system that could identify and track the enemy, predict where it would be, and automatically destroy it. This involved issues like the system's response to noise, human operators swamped with information from radar which they could not process quickly enough, and so on. This encouraged the development of a systems approach. Ivan Getting defined the system as a single entity comprising signals, dynamics, time constants, and feedback that needed to be *defined together in advance*. He redefined the role of the Radiation Lab and himself as a *systems integrator* operating between the government and contractors on engineering, production, testing, alignment, and training. He therefore demanded access to all relevant correspondence, drawings, tests and so on. These new ideas helped Getting develop the only successful fully automatic radar-controlled fire-control system ('the Mark 56 System').[3]

Manhattan Project and the end of the war

I will write separately about aspects of the *Manhattan Project*. It obviously was the great wartime example of how a set of people had to overcome simultaneously problems with basic science, technology development, complex project management, and extreme political issues. The Manhattan Project also opened the eyes of senior politicians and generals to the possibilities of having world-class physicists work on defence problems beyond just the technical issues. Physicists did not just build the bomb. They were intimately involved in issues such as the correct bombing strategy of Japan and which cities to target for the first nuclear weapons.

The generals also set up institutions after the war to develop ideas such as OR and 'systems analysis'. The Air Force set up the Scientific Advisory Board under Caltech professor von Karman. The most famous was the RAND Corporation in Santa Monica, the prototype defence think tank established by the USAF. Cf. p.164ff of my essay for some history of RAND, and *The Wizards of Armageddon* (Fred Kaplan) which explores the role of RAND in developing nuclear strategy.

The main practical problem the generals soon confronted was the Soviet test of a hydrogen bomb and the possibilities of it being delivered by missile.

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John von Neumann and new interdisciplinary ideas from physics and maths to computers, information, and 'systems'

During the 1930s and 1940s the combination of scientific breakthroughs, technological development, and the pressure of World War II led to the synthesising of ideas across fields and integration in new fields. The work of Gödel and Turing in the 1930s laid theoretical foundations for the digital computer. Shannon introduced *Information Theory* giving precise equations for

[3] Cf. *Automation's Finest Hour*, Mindell.

calculating, 'noise' and 'signal'.[4] Wiener wrote *Cybernetics* about the integration of man and machine in new cybernetic systems. Schrödinger wrote *What is Life?* combining ideas from thermodynamics and evolution. As the development of technologies became ever more complex and ever more entangled with questions of policy and management, ideas about *'systems engineering' and 'systems management'* evolved in this fertile ecosystem of related ideas.

John von Neumann was involved in or central to many of these developments. He was one of the leading mathematicians of the 20th Century. He also made a major contribution to the mathematisation of quantum mechanics and wrote the first paper on 'quantum logic' (1936). During the war he worked on many OR problems including the Manhattan Project. At the same time he wrote the classic '*Theory of Games and Economic Behaviour*' which founded the field of game theory. It is telling that he refused to review Paul Samuelson's *Foundations of economic analysis*, one of the most influential books in modern economics.

> 'If those books are unearthed sometime a few hundred years hence, people will not believe they were written in our time. Rather they will think they are about contemporary with Newton, so primitive as their mathematics. Economics is simply still a million miles away from the state in which an advanced science is such as physics. Samuelson has murky ideas about stability. He is no mathematician.' (Cf. HERE for a discussion of his ideas on mathematics and economics *which every PPE-ist should be forced to study.* After his death game theory developed, partly because of Nash's influence, in ways vN disapproved of.)

With Alan Turing he did the most important theoretical and practical work in developing electronic digital computers and the field of artificial intelligence. Almost all modern computers use 'von Neumann architecture' (cf. '*The First Draft of a Report on the EDVAC*'). His experience of the Manhattan Project then, after the war, developing the first digital computers and the hydrogen bomb also exposed him to the problems of managing large scale technology projects and this would lead him to support new management ideas for the ICBM programme.

After the war he also worked on weather forecasting in parallel with building his computer at the IAS (Princeton). In 1945-6, he became convinced that meteorology ought to be its practical focus because the hydrodynamics of the atmosphere presented precisely the sort of nonlinear problem that computers could potentially revolutionise. He envisaged a network of computers across the globe sharing information on weather patterns. In 1950, the first computerised weather forecasts were performed. By 1952, several military agencies were developing similar programs with IAS's help. Over the next ten years, the entire field of meteorology was revolutionised. Von Neumann was interested not only in weather forecasting but in weather *control*. He envisaged that weather control could significantly improve the environment in various parts of the earth and could also be used as a weapon though he generally played down these possibilities in conversations with meteorologists.[5]

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[4] Ideas linking physics and information began in the 19th Century with thermodynamics and the infamous 'Maxwell's Demon'. Shannon's '*A Mathematical Theory of Communication*' (1948) is the founding text of information theory and introduced the idea of treating information like entropy in physics as a measure of disorder or uncertainty. 'My greatest concern was what to call it. I thought of calling it 'information', but the word was overly used, so I decided to call it 'uncertainty'. When I discussed it with John von Neumann, he had a better idea. Von Neumann told me, "You should call it entropy, for two reasons. In the first place your uncertainty function has been used in statistical mechanics under that name, so it already has a name. In the second place, and more important, nobody knows what entropy really is, so in a debate you will always have the advantage."'

[5] In 1961, Lorenz, who had briefly studied under von Neumann, was playing with a computerised weather model when one night a serendipitous oddity revealed to him what he would call 'chaos theory' (cf. p.136 HERE).

Between the end of the war and his death in 1957, von Neumann also wrote a series of papers and lectures concerning the whole range of issues involved in computation and sought to establish 'a logical theory of automata and information'. He gave the first proof of the possibility of self-replicating machines (which paved the way for the field of 'Artificial Life') which also proved that reliable complex systems can be built using *un*reliable parts. This work included, *inter alia*:

(i) *The General and Logical Theory of Automata* (delivered 1948, published 1951).
(ii) Five lectures on *Theory and Organization of Complicated Automata* (delivered in 1951).
(iii) *The Theory of Automata*, a manuscript written 1952–3 but unpublished until after his death.
(iv) *The Computer and the Brain*, drafts for the Sulliman lectures supposed to be delivered to Yale in spring 1956, written 1955 – 6, but unpublished until 1958.

Because of his great workload and then cancer, he never got his thoughts into a final published form. The book '*Theory of Self-Reproducing Automata*', published in 1966 (edited by Arthur Burks), comprised edited versions of (ii) and (iii).

The work he did 1945-56 therefore combined 1) attacking practical problems such as building computers, weather forecasting, the hydrogen bomb, and ICBMs as well as participation in many other committees and projects devoted to national security and technology, and 2) a set of ideas linking logic and computation, physics, the mind, information theory, artificial intelligence and life, economic modelling, and fundamental mathematics. He spent much time pondering how machine intelligence and combining man and machine in more effective systems could help avoid nuclear destruction.

At the heart of all this was a fundamental problem: the inadequacies of conventional mathematics for *making predictions about complex non-linear systems*. He had confronted a variety of problems with fluid dynamics, shockwaves, and turbulence during the war. The inadequacies of conventional mathematics for dealing with non-linear systems was a big motivation for developing the computer. He hoped that computers would provide an alternative to the conventional scientific process of – observe, hypothesise, predict, experiment – by allowing simulations and heuristic use of computers, 'the methods of automatic perception, association, organization and direction'.

> 'Our present analytical methods seem unsuitable for the solution of the important problems arising in connection with non-linear partial differential equations and, in fact, with virtually all types of nonlinear problems in pure mathematics... A brief survey of ... most of the successful work in pure and applied mathematics suffices to show that it deals in the main with linear problems... The advance of analysis is, at this moment, stagnant along the entire front of non-linear problems…
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> '[M]any branches of both pure and applied mathematics are in great need of computing instruments to break the present stalemate created by the failure of the purely analytical approach to the non-linear problems... [R]eally efficient high speed computing devices may, in the field of non-linear partial differential equations as well as in many other fields ... provide us with those heuristic hints which are needed in all parts of mathematics for genuine progress' (Large-Scale High Speed Computing, von Neumann & Goldstine).

This problem and his work on self-replicating automata also led him to consider the differences between self-repairing evolved biological systems and fragile engineered systems.

> '[I]f a living organism is mechanically injured, it has a strong tendency to restore itself. If ... we hit a man-made mechanism with a sledge hammer, no such restoring tendency is

apparent... It's very likely that on the basis of the philosophy that every error has to be caught, explained, and corrected, a system of the complexity of the living organism would not run for a millisecond.'

Towards the end of the war, von Neumann returned home one night from Los Alamos. He woke his wife and talked to her about the atomic bomb, automation, and the possibilities to develop space flight. He was in an unusual state of mind and she wrote down what he said:

> 'What we are creating now is a monster whose influence is going to change history, provided there is any history left… [i.e. the atomic bomb] This is only the beginning… The world could be conquered, but this nation of puritans will not grab its chance; we will be able to go into space way beyond the moon if only people could keep pace with what they create.'

In conversation with Stan Ulam, he described the ever-accelerating pace of technological development **'which gives the appearance of approaching some essential singularity in the history of the race beyond which human affairs, as we have known them, cannot continue.'**

In 1955, he wrote '*Can We Survive Technology?*' Unlike many brilliant men he had grasped immediately the nature of the Nazi and Stalinist regimes and the likelihood of war. He had a great interest in and feel for history. Much of his work in this field was classified, some if it still so, but he did write a public essay about the basic problems.

> '"The great globe itself" is in a rapidly maturing crisis — a crisis attributable to the fact that the environment in which technological progress must occur has become both undersized and underorganised…
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> 'In the first half of this century the accelerating industrial revolution encountered an absolute limitation — not on technological progress as such but on an essential safety factor. This safety factor, which had permitted the industrial revolution to roll on from the mid-eighteenth to the early twentieth century, was essentially a matter of geographical and political *Lebensraum*: an ever broader geographical scope for technological activities, combined with an ever broader political integration of the world…
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> 'Now this safety mechanism is being sharply inhibited; literally and figuratively, we are running out of room. At long last, we begin to feel the effects of the finite, actual size of the earth in a critical way.
>
> 'Thus the crisis does not arise from accidental events or human errors. It is inherent in technology's relation to geography on the one hand and to political organization on the other…
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> 'In all its stages the industrial revolution consisted of making available more and cheaper energy, more and easier controls of human actions and reactions, and more and faster communications. Each development increased the effectiveness of the other two. All three factors increased the speed of performing large-scale operations — industrial, mercantile, political, and migratory. But throughout the development, increased speed did not so much shorten time requirements of processes as extend the areas of the earth affected by them. The reason is clear. Since most *time* scales are fixed by human reaction times, habits, and other physiological and psychological factors, the effect of the increased speed of technological processes was to enlarge the *size* of units — political, organizational, economic, and cultural — affected by technological operations. That is, instead of

performing the same operations as before in less time, now larger-scale operations were performed in the same time. This important evolution has a natural limit, that of the earth's actual size. The limit is now being reached, or at least closely approached…

'The advent of nuclear weapons merely climaxes the development. Now the effectiveness of offensive weapons is such as to stultify all plausible defensive time scales. As early as World War I, it was observed that the admiral commanding the battle fleet could "lose the British Empire in one afternoon." Yet navies of that epoch were relatively stable entities, tolerably safe against technological surprises. Today there is every reason to fear that even minor inventions and feints in the field of nuclear weapons can be decisive in less time than would be required to devise specific countermeasures. Soon existing nations will be as unstable in war as a nation the size of Manhattan Island would have been in a contest fought with the weapons of 1900.

'Also likely to evolve fast — and quite apart from nuclear evolution — is automation… Fundamentally, improvements in control are really improvements in communicating information in an organisation or mechanism. The sum total of progress in this sphere is explosive… Probably intervention in atmospheric and climatic matters will come in a few decades, and will unfold on a scale difficult to imagine at present…

'All this will merge each nation's affairs with those of every other…

'[First] Technology — like science — is neutral all through, providing only means of control applicable to any purpose, indifferent to all…

'Second, there is in most of these developments a trend toward … producing effects that can be projected from any one to any other point on the earth. There is an intrinsic conflict with geography — and institutions based thereon — as understood today… The technology that is now developing and that will dominate the next decades seems to be in total conflict with traditional and, in the main, momentarily still valid, geographical and political units and concepts. This is the maturing crisis of technology…

'It is not a particular perverse destructiveness of one particular invention that creates danger. Technological power, technological efficiency as such, is an ambivalent achievement. Its danger is intrinsic…

'The crisis will not be resolved by inhibiting this or that apparently particularly obnoxious form of technology… [U]seful and harmful techniques lie everywhere so close together that it is never possible to separate the lions from the lambs… [T]he banning of particular technologies would have to be enforced on a worldwide basis. But the only authority that could do this effectively would have to be of such scope and perfection as to signal the resolution of international problems rather than the discovery of a means to resolve them…

[Heading: 'Survival — a possibility']

'A much more satisfactory solution than technological prohibition would be eliminating war as "a means of national policy."… Whether the "practical" considerations … will suffice to restrain the human species is dubious since the past record is so spotty … [and] there is no guarantee that a real danger can control human actions…

'What safeguard remains? Apparently only day-to-day — or perhaps year-to-year — opportunistic measures, a long sequence of small, correct decisions. And this is not surprising. After all, the crisis is due to the rapidity of progress, to the probable further acceleration thereof, and to the reaching of certain critical relationships. Specifically, the effects that we are now beginning to produce are of the same order of magnitude as that of "the great globe itself." Indeed, they affect the earth as an entity. Hence further acceleration can no longer be absorbed as in the past by an extension of the area of operations. Under present conditions it is unreasonable to expect a novel cure-all.

'**For progress there is no cure**. [emphasis added] Any attempt to find automatically safe channels for the present explosive variety of progress must lead to frustration. The only safety possible is relative, and it lies in an intelligent exercise of day-to-day judgment.

'Present awful possibilities of nuclear warfare may give way to others even more awful… We should not deceive ourselves: once such possibilities become actual, they will be exploited. **It will, therefore, be necessary to develop suitable new political forms and procedures.** All experience shows that even smaller technological changes than those now in the cards profoundly transform political and social relationships. Experience also shows that these transformations are not *a priori* predictable and that most contemporary "first guesses" concerning them are wrong…

'Can we produce the required adjustments with the necessary speed? The most hopeful answer is that the human species has been subjected to similar tests before and seems to have a congenital ability to come through, after varying amounts of trouble. To ask in advance for a complete recipe would be unreasonable. We can specify only the human qualities required: patience, flexibility, and intelligence.'

Looking at the economy and technology 60 years later we can see that this picture has only become more worrying.

The 'present awful possibilities' have indeed given way to 'others even more awful'. Banning certain technological development remains as impractical as ever. There is no reasonable prospect of the post-war institutions like the UN solving these problems. We have relied on 'an intelligent exercise of day-to-day judgment' and this has nearly been fatal on many occasions. As yet there have not been the 'suitable new political forms and procedures' that provide hope of doing things much better.

In autumn 1955 von Neumann was diagnosed with cancer and by early 1956 he was confined to a wheelchair. He never gave his planned lectures on *The Computer and the Brain*. He agreed to move to UCLA where he would have had a unique position explicitly connecting mathematics, physical sciences, and fields such as meteorology, economics and management but he could not make the move. He entered Walter Reed hospital and died on 8 February 1957. Many senior figures in the US Government and military visited him to thank him for his service.

For those interested the appendices to my 2013 essay contain more detail on some of this history.

Hydrogen bombs, ICBMs, and extreme management problems

The first hydrogen bomb was tested in 1952. It was quickly clear that it would be possible to deliver them using intercontinental missiles. Both America and Russia had nabbed German engineers from the Nazi wartime rocket programme and put them to work. Repeated US missile failures in the 1950s were embarrassing and sparked scrutiny. The Soviets' launch of the Sputnik satellite in 1957 launched the space race and provoked even more urgent efforts.

Managers and writers on management such as Drucker had grappled in the 1940s with the issue of how scientists, engineers, and innovation fit with Taylor's ideas of 'scientific management'. Their knowledge and skills were beyond almost all normal managers. The insights and innovations they generated could not be routinised as per Taylor's methods. Drucker suggested 'management by objectives' whereby managers and professionals jointly negotiated aims for the firm and individuals. This worked for some projects. It did not work on more complex projects.

Missiles, air defence, and space flight posed entangled extreme problems. The *space environment* was extreme (e.g. no air to help cooling), the volatility of *rocket fuel* was extreme (e.g vibrations shook the whole vehicle and transcended the problems of individual specialties), *interference problems* were extreme (e.g. signals interfered with other very new and sensitive equipment), and *automation demands* were extreme (e.g. new sensors and computer systems were needed, many decisions had to be taken faster than humans could take them and so on). The management demands in these areas were therefore also extreme.

In 1953, a relatively lowly US military officer Bernie Schriever heard von Neumann sketch how by 1960 the United States would be able to build a hydrogen bomb weighing less than a ton and exploding with the force of a megaton, about 80 times more powerful than Hiroshima. Schriever made an appointment to see von Neumann at the IAS in Princeton on 8 May 1953. As he waited in reception, he saw Einstein potter past. He talked for hours with von Neumann who convinced him that the hydrogen bomb would be progressively shrunk until it could fit on a missile. Schriever told Gardner about the discussion and 12 days later Gardner went to Princeton and had the same conversation with von Neumann. Gardner fixed the bureaucracy and created the Strategic Missiles Evaluation Committee. He persuaded von Neumann to chair it and it became known as 'the Teapot committee' or 'the von Neumann committee'. The newly formed Ramo-Wooldridge company, which became Thompson-Ramo-Wooldridge (I'll refer to it as TRW), was hired as the secretariat.

The Committee concluded (February 1954) that it would be possible to produce intercontinental ballistic missiles (ICBMs) by 1960 and deploy enough to deter the Soviets by 1962, that there should be a major crash programme to develop them, and that there was an urgent need for a new type of agency with a *different management approach* to control the project. Although intelligence was thin and patchy, von Neumann confidently predicted on technical and political grounds that the Soviet Union would engage in the same race. It was discovered years later that the race had already been underway partly driven by successful KGB operations. Von Neumann's work on computer-aided air defence systems also meant he was aware of the possibilities for the Soviets to build effective defences against US bombers.

> 'The nature of the task for this new agency requires that over-all technical direction be in the hands of an unusually competent group of scientists and engineers capable of making *systems analyses*, supervising the research phases, and completely controlling experimental and hardware phases of the program… It is clear that the operation of this new group must be relieved of excessive detailed regulation by existing government agencies.' (vN Committee, emphasis added.)

Gardner later explained, ‘What bothered the scientists was that in peacetime the cumbersome time-consuming machinery of government could not be streamlined to permit the swift mobilisation of the necessary resources.’ Von Neumann and the others knew that no existing company or organisation could do such a complex job and it required a new organisation and a new management approach.

A new committee, the ICBM Scientific Advisory Committee, was created and chaired by von Neumann so that eminent scientists could remain involved. One of the driving military characters, General Schriever, realised that people like von Neumann were an extremely unusual asset. He said later that ‘I became really a disciple of the scientists… I felt strongly that the scientists had a broader view and had more capabilities.’ Schriever moved to California and started setting up the new operation but had to deal with huge amounts of internal politics as the bureaucracy naturally resisted new ideas. The Defense Secretary, Wilson, himself opposed making ICBMs a crash priority. After delays and problems, President Eisenhower met von Neumann on 28 July 1955.[6] On 13 September Eisenhower signed NSC Action No. 1433, the presidential directive that made clear to the bureaucracy that he supported ‘a research and development program [for ICBMs] of the highest priority above all others.’ Schriever later said:

> ‘We got out of that report [the Teapot Committee] a portion that was signed by von Neumann himself, in which he pointed out that we would never be able to get it done unless we changed our management structure so that bureaucracy couldn’t stop you at various detailed levels, that you needed a special management approach for the ICBM program… It turned out that we had a unique management approach that’s not around anymore… Management was the key… Accomplishing a management approach that is streamlined in the decision-making process, and got … Eisenhower behind it, probably was the most challenging job I had… I know a hell of a lot of people were fighting like mad to prevent that management approach to be undertaken, because it broke up a little china here and there….
>
> ‘Management is our theme because management is our need. Increased scientific and engineering competence will not speed up the rate of our technical progress unless we learn to manage our resources more wisely and efficiently. In systems acquisition today, management is the pacing factor…
>
> ‘If you want to move fast, you have got to get yourselves out from under that red tape, or you just can't move.’

Schriever’s August 1954 study of the issue concluded that ‘the predominant technical aspects of this project have to do with systems engineering and with the close relationship of recent physics to all engineering’ and a single industrial organisation ‘generally lack[s] the across-the-board competence in the physical sciences to do the complex systems engineering job which the ICBM requires.’ TRW had already proved able to do this job and were already attracting the country’s top talent. Von Neumann and his committee helped get them working for Schriever.

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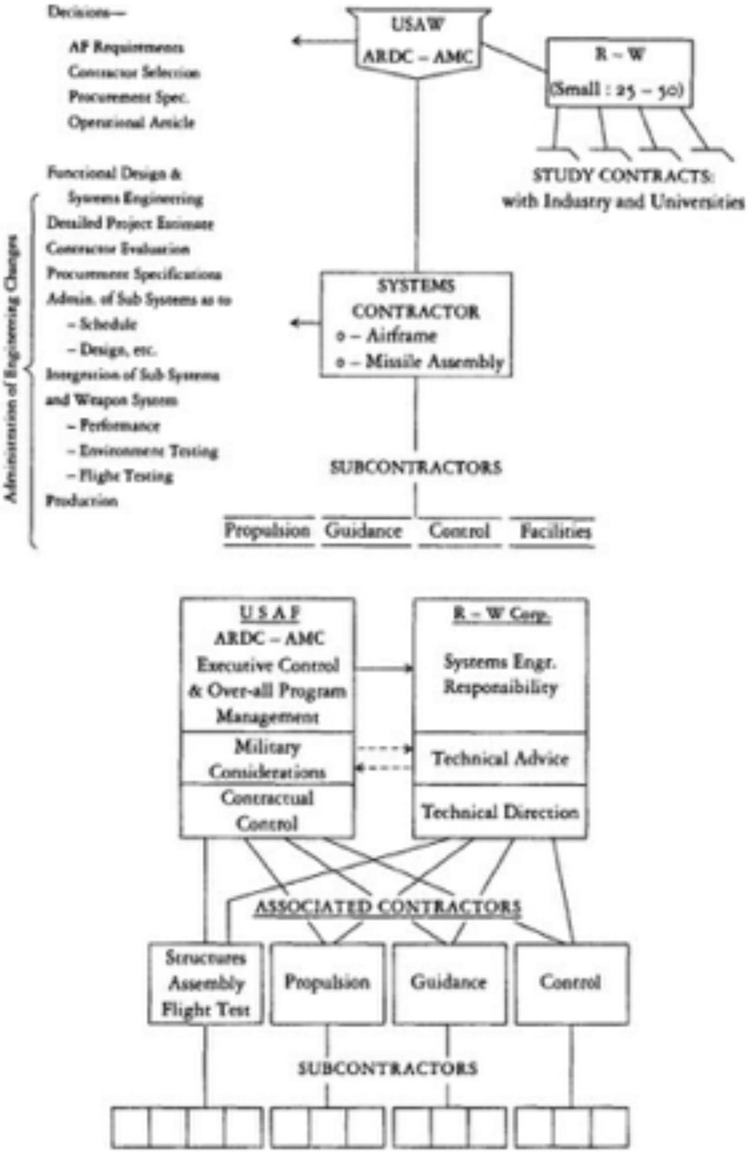
[6] A few weeks later von Neumann learned that he had cancer. He returned to brief a NSC meeting on 8 September. For a detailed account of the classic bureaucratic manoeuvres necessary to get von Neumann in front of Eisenhower against the wishes of powerful elements, see chapter 46, Sheehan 2009.

Picture: the top half shows the traditional 'prime contractor' system, the bottom half shows the new structure with TRW as the systems engineer (from August 1954 study by Schriever's team)



TRW was appointed for systems engineering and integration. Schriever then had to fight to remove endless tiers of the government bureaucracy demanding the right of approval and endless people who could say 'no' but not 'yes' that immediately stymied progress despite the supposed 'top priority'. There were about 40 different branches of government that could interfere and a mindset dominated by normal regulation and lawyers. He went to Gardner and explained the problem and said he 'could not possibly get the … job done if I have to go through all this crap'.

Gardner, skilled in bureaucratic infighting, created a stacked committee that managed to prise almost all the normal bureaucratic hands off the ICBM project ('*the Gillette Procedures*', cf. p.40-1, Johnson). Schriever now only needed *a single approval of a single document each year*. Schriever and TRW were given great scope to evade normal government rules including for personnel and procurement. According to Johnson, this was a first for the Air Force 'where the project manager had both technical and budgetary authority' as previously every project drew funds from several budgets and required separate processes for making decisions. Insiders said later it would have been declared illegal if it had not been a classified project.

Almost everybody hated the arrangement. Even the Secretary of the Air Force (Talbott) tried to overrule Schriever and Ramo. It displaced the normal 'prime contractor' system in which one company, often an established airplane manufacturer, would direct the whole programme. Established businesses were naturally hostile. Traditional airplane manufacturers were run very much on Taylor's principles with rigid routines. TRW employed top engineers who would not be organised on Taylor's principles. Ramo, also a virtuoso violinist, had learned at Caltech the value of a firm grounding in physics and an interdisciplinary approach in engineering. He and his partner Wooridge had developed their ideas on systems engineering before starting their own company. The approach was vindicated quickly when TRW showed how to make the proposed Atlas missile much smaller and simpler therefore cheaper and faster to develop.

Armed with his unprecedented authority, Schriever pursued what became known as '*concurrency*' — pursuing several options in parallel 'in the interest of compressing time — our most critical commodity'. Groves had done the same on the Manhattan Project. The engineers developed much more rigorous systems for exhaustive testing, component inspection and tracking, and 'configuration control'. Managers developed much more rigorous systems for cost control and planning.

Gradually, with TRW playing a vital role, the principles of systems engineering were hashed out. They built new long-distance phone systems including encrypted links and teletype facilities. Schriever believed they may have been the first military programme to use digital computers to process control room information. Schedules were standardised across all the different players and coordinated centrally but in such a way that managers could access them and see quickly the status of the project.[7] 'Black Saturdays' were monthly days on which the whole project was reviewed and responsibility for all problems assigned to individuals. They were 'black' because the purpose was to discuss the bad news. 'Give me the bad news. I can take it. I will not fire you for giving me the bad news. I will fire you if you don't give me the bad news', Schriever said (echoing Warren Buffett: gimme the bad news, the good news can wait). If they hit apparently intractable technical problems, calls would go out to von Neumann's committee for scientific help.

'*Matrix management*' allowed organisations to manage projects using people spread across different functional departments all reporting to a project manager as well as their department head. '*Configuration control*' and '*configuration management*' connected changes to specifications, designs, hardware, and operational and testing procedures within an overall system for scheduling. Engineers were required to give schedule and cost estimates with requests for any technical change, allowing managers to monitor what was happening and who was slipping. All changes had to be notified, approved, and then communicated widely. It allowed the engineers to coordinate subsystems. Before this, said one involved, 'we didn't have a record of how we made it successful. So we were having random success, the worst thing that can happen to you because you know you got it right but you can't repeat it.' It allowed the accountant and legal experts to see the ties between cost and scheduling documents and contractual documents. *Minuteman*, the new ICBM project, was developed using configuration management and was much more successful. (Cf. p. 79-80, Johnson.)

The other project that sparked the development of systems management was the novel air defence project SAGE - Semi−Automatic Ground Environment (SAGE) Air Defense System. This also involved von Neumann. It was the first digital computer-based real-time information-processing centre for a complex command and control weapon system. It grew out of an MIT project

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[7] Two tools that emerged were 'Program Evaluation Review Technique' (PERT), a project management tool developed by the US Navy's missile program Polaris that rapidly spread to civilian companies, and Critical Path Method (CPM).

WHIRLWIND at the end of the war run by Jay Forrester. This was arguably the beginning of the story of the development of autonomous weapons — one of the most important issues we now face. SAGE itself did not work out as planned. It did though help develop expertise in systems management as well as create a large well-funded hub of expertise in all aspects of the emerging field of computer science and many of those involved would go on to work on projects such as ARPANET. By funding so many people to become expert in computer science it also led to the rapid spread of computers outside the military and the growth of IBM and others. In 1962, IBM delivered the world's first computerised reservation system to American Airlines.

According to Johnson, almost all the proponents of systems engineering had connections with either Caltech (where von Karman taught and JPL was born) or MIT (which was involved with the Radiation Lab and other military projects during World War 2). Bell Labs, which did R&D for AT&T, was also a very influential centre of thinking. The Jet Propulsion Laboratory (JPL) managed by Caltech also, under the pressure of repeated failure, independently developed systems management and configuration control. They became technical leaders in space vehicles. NASA, however, did not initially learn from JPL.

After the success of systems management and concurrency with ICBMs, the Pentagon changed direction. After Sputnik in 1956 Eisenhower pushed through the Defense Reorganisation Act in 1958. This gave the Pentagon and Secretary of Defense far more power over the services' budgets. In 1960 Kennedy became President and brought in McNamara. They soon realised that extremely closely guarded satellite reconnaissance (the classified CORONA programme) showed that the supposed 'missile gap' touted by Kennedy in the 1960 election was a fiction (as Eisenhower knew but could not say).[8]

The combination of new powers and less urgency led to changes in R&D and project management. Ironically, the Pentagon started to use the methods that the entrepreneurial Schriever and TRW had developed to control Schriever himself and others: Schriever's methods 'provided the basis upon which McNamara could then control all military R&D programs' (Johnson). Powers over R&D were centralised and new bureaucratic requirements were imposed. McNamara also pushed to replace concurrency with 'phased planning' - i.e. developing projects sequentially rather than in parallel. Overall the Pentagon became more powerful and consciously emphasised *cost issues over performance issues*: state-of-the-art performance was less of a priority.

Schriever and Phillips thought the new system had serious flaws. Phillips wrote that the Minuteman program already defined what was necessary in advance and therefore provided a basis to optimise cost, performance, or time. Schriever complained about the 'disturbing trend' of 'creeping centralization' in the Pentagon.

> 'If we are to be held to this overly conservative approach, I fear the timid will replace the bold and we will not be able to provide the advanced weapons that the future of the nation demands.' Schriever.

McNamara, someone who had risen at Ford by his success in controlling budgets, ignored complaints. The successes with ICBMs and other projects did lead to a rapid spread of systems engineering/management ideas. In 1964 the Engineering Index had no entry for 'systems engineering'. By 1969 there were 8 pages of citations. Companies like the Bechtel Corporation spread the ideas into the civilian economy. A big part of the reason was what happened at NASA.

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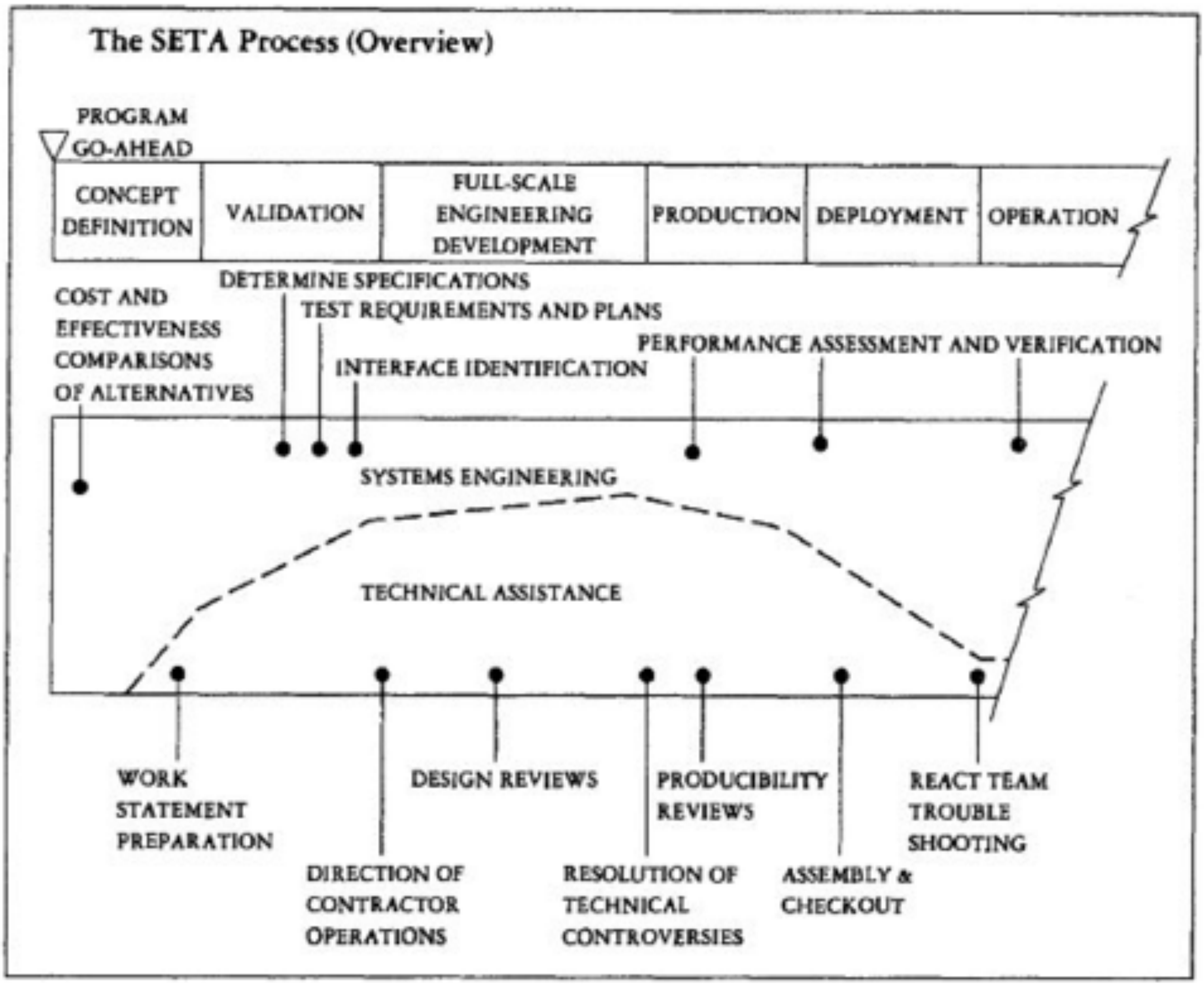
[8] According to Mueller some at NASA were kept in the loop on some findings from this programme during the 1960s which I find very surprising.

Graphic: the TRW systems engineer / technical assistance process



Mueller and systems management: putting man on the moon

'Fascinating that the same problems recur time after time, in almost every program, and that the management of the program, whether it happened to be government or industry, continues to avoid reality… [S]o many programs fail because everybody doesn't know what it is they are supposed to do' (Mueller).

In 1961 President Kennedy announced the national goal of a manned mission to the moon by the end of the decade.[9] Apollo was a massive task involving different NASA centres. In many areas it was brilliant *technically*. It enjoyed huge good will and a clear goal (unlike the European project ELDO, see below). It was however thoroughly deficient *managerially* given the scale and complexity of the project and budgets were out of control.

Mueller worked at the famous Bell Labs where he first saw some the problems with big projects while working on airborne radar. At TRW he saw the then state-of-the-art in systems engineering and systems management working on missiles and space. He was then chosen to run the Apollo programme for NASA. He was a dedicated man who worked extremely hard and demanded the same of others. Seamans called him 'a double whirlwind... The days of the week meant nothing to him.' He inevitably ruffled many feathers but he was sure of the fundamentals of systems management and knew they would never reach the moon by 1970 unless he forced it upon the whole gigantic mess. 'George didn't sell; he dictated - and without his direction, Apollo would not have succeeded' (Seamans). He was also helped enormously by an extremely capable US Major General called Samuel Phillips who had also worked on the missile programme.

Simon Ramo, co-founder of TRW, defined systems engineering as: 'the design of the whole as distinct from the design of the parts. Systems engineering is inherently interdisciplinary because its function is to integrate the specialized separate pieces of a complex of apparatus and people — the system — into a harmonious ensemble that optimally achieves the desired end.' He described a 'systems engineer' as 'a peculiar form of generalist [with] the faculty of understanding enough of each of the pieces and [is] good at communications.' Elsewhere Ramo defined it:

> '[The systems approach] depends upon use of a team of cooperating experts in both the technological and nontechnological aspects of the problem to be analyzed. It starts by definition of goals and ends with a description or a design of a harmonious, optimum ensemble of the required men and machines, with such a corollary network of flow of information and materials as will cause this system to operate to solve the problem or to fill the need. The approach includes use of sophisticated techniques for assembling and processing the necessary data, comparing alternative approaches to evaluate the relative benefits and shortcomings, providing compromises, making quantitative analyses and predictions where they are appropriate, and seeking out judgements from experience of the past and creative innovations where, in turn, they are indicated. Resting in part on the computer to assist in weighing and relating facts and relationships, *the systems approach is an extended, if somewhat automated, common sense. It is more especially a reasoned and total, rather than a fragmentary, look at problems, seeking to push confusion and hit-or-miss decision-making into the background and leaning heavily on rational, concrete judgements.*' (Emphasis added.)

Mueller defined 'systems management' as: 'a structure for visualizing all the factors involved as an integrated whole, much as system engineering visualizes all of the physical aspects of a problem.' It is really, he said, system engineering applied to management and permits the system manager to

[9] The science community generally opposed the lunar mission in the early 1960s and this increased pressure on budgets.

'recognize the nature and interaction of complex procedures in advance of their becoming problems.'

> 'It requires you to really understand all of the forces that are brought to bear on a particular system and you've got to take account of "whatever" or else the system won't work the way it's supposed to.' Mueller.[10]

The heart of the idea was the need to ensure that the project was managed with an overall understanding of the *whole system* so that all the complex parts were properly *integrated*. Many of the failures came from the failure of integration and problems with technical and schedule compatibility of *interfaces*. Integrating the system required integrating disparate teams and specialised expertise (scientists, engineers, military officers, managers) and building an *organisation-wide orientation* so that everybody had an understanding of the whole. All aspects of the organisation therefore had to *communicate* in much richer, deeper ways than had been normal in traditional organisations working in silos so that 'all of us understand what was going on throughout the program… [C]ommunications on a level that is free and easy and not constrained by the fact that you're the boss… [This was] the secret of the success of the program, because so many programs fail because everybody doesn't know what it is they are supposed to do' (Mueller). All aspects of the management system were reshaped including planning, documentation, inspection and testing to coordinate the efforts of very large *interdisciplinary* teams.

Mueller required the different NASA centre bosses (Florida, Texas etc) to report directly to him. He introduced a 'matrix management' system whereby teams in the centres reported both to his HQ and to their centre's bosses. He then required the different teams, in different NASA centres, to communicate constantly with their functional counterparts at other centres and on other teams. His 'five box' structure meant that the five teams at HQ were copied in each centre: *program control, systems engineering, testing, reliability, and flight operations*. Managers and engineers in each box talked directly to their HQ equivalents outside their centre's chain of command. One individual was clearly responsible for each key area and was strongly empowered by Mueller who did not bypass the chain of command: 'You've got to have people feeling responsible and holding them responsible for the results in each of these major areas' (Mueller). 'Daily communications down those five parallel lines is probably the most significant contribution to getting the program done that I know of' (Mueller). Many air force personnel with experience in systems management were brought to NASA.

Contractors were brought in-house and required to immerse themselves in the whole project. He ensured there was a committee of the CEOs of major contractors meeting with NASA and another committee that met beforehand of more junior people who would brief their bosses. Communication spread and people knew their bosses would have visibility of their work. When he started he would call the CEO of Boeing and ask 'what happened to that valve?' The CEO had no idea. As the new system embedded the CEOs became personally involved in the project and when Mueller called they would know about the specific problems. Mueller also built personal relationships with them and spent time giving speeches at their companies. It is 'amazing if you can get the CEO to come and see what the total program is and what his group's problems are, how rapidly those problems get addressed and solved.' He also rewrote many of the contracts to align them with the emerging agreed design and so that they were *incentivised to hit schedules*, which Mueller was understandably obsessed with. This also focused NASA people on defining exactly what they wanted.

[10] Stephen Johnson, author of *The Secret of Apollo*, defines 'systems management' as: 'a set of organisational structures and processes to rapidly produce a novel but dependable technological artefact within a predictable budget.' This seems to leave out the vital role of *integrating information about interactions across the system*.

Configuration management, as developed on missiles, was imposed. He described the essence of the method as: 'you define at each stage what you think the design is going to be within your present ability. After you describe it you let everybody know what it is when you change it.' Contractors could only change things that did not affect anyone else. Only program managers could authorise changes that affected interfaces and other things with effects across the whole system. To those who objected Mueller replied that the first ICBMs built with configuration management were the first delivered within budget and schedule, despite combining liquids and solids.

Like with ICBMs, Mueller pursued *concurrent development* of some systems. Although this was criticised as wasteful, Mueller always argued that it *saved lots of money in the long-term* and the real problem is that Congress and politicians do not think long-term. His view was that it would have been cheaper and more productive long-term to use concurrent development more widely than he was able to given his budget constraints. 'Time is money', he told people repeatedly: *if you save lots of time, you save lots of money*.

He also scrapped the conservative and lengthy testing schedule that would test each stage before proceeding to the next. Instead there would be *'all-up testing'* with all elements active and as close to lunar configuration as possible:

> 'I want to test it and test it and test it at a subsystem level. However, at a system level you're much better off testing the system because in the end that system has to work. And then the only way you find out is if you test it as a system… You can plan for disaster or you can plan for success. You might as well plan for success because you will have the disasters anyway… If you lost a vehicle, you were likely to lose it at any stage so you might as well go as far as you can and find out where the problems are… [You] don't decrease the risks by testing sequentially; you only spread the risk out.'

The speed and precision of *information sharing* were rapidly improved. Instead of monthly updates, Mueller wanted daily updates. All data were displayed in a central control room that had automated displays from other field centers. They even spent time building specialised communications systems such as a 'teleservices network' to connect the teams and data and provide the ability to hold teleconferencing. *Information was updated fast and shared widely.* A new control room was built based on that built for Minuteman. He inherited a *management council* of 14 at the apex of the hierarchy and cut it to 4 (himself and the three centre directors) and made it a real part of the decision making process so that 'everybody knew what everybody was doing'. Overall, there was a complex mix of centralisation and decentralisation with Mueller giving people very wide powers to make decisions themselves and devolve further.

Initially Mueller's approach caused a lot of internal unhappiness. 'Words like impossible, reckless, incredulous, harebrained, and nonsense could be heard behind the scenes' (Seaman). Von Braun and other brilliant engineers protested. Mueller pressed on. 'George was indomitable. He didn't believe in weekends' said Seamans. Von Braun, whom Mueller greatly respected as an 'outstanding engineer' and an 'outstanding charismatic leader', eventually acknowledged Mueller was right: 'The real mechanism that makes [NASA] 'tick,' is … a continuous cross-feed between the right and left side of the house.' Von Braun said that he, a mechanical engineer, saw organizations as reductionist contraptions while Mueller brought the perspective of an electrical engineer who wanted a managerial 'nervous system'. By 1968, he was converted to the new approach as he saw its overall necessity and saw how it could add value even for his brilliant team.

Europe's ELDO failure

In 1961 European technology and technical expertise were roughly similar to those of the United States. Europe did not have equivalents to America's business schools or the experience of building something like ICBMs at a European level.

Each country tried to get more out of ELDO than it put in and withheld information from it. Each country contributed according to fixed proportions but spent according to costs, so each had an incentive to overrun on costs. Budgeting was an inevitable disaster. Projects were spread across countries, agencies, and contractors. There was no systems management. There was never a single complete specification for the vehicle. Communication overall was normal for a huge project without proper management - very poor. Costs spiralled, schedules were missed, and data stayed in silos. Integration was a disaster. Each launch failed.

In 1968 an internal NASA report described ELDO's teamwork as 'half-hearted and mutually-suspicious'. ELDO 'combined many of the worst management ideas into a single pitiful organization' with a 'fatally flawed management structure… Systems management required critical attention to interfaces but ELDO initially ignored them' (Johnson).

ELDO never successfully launched. Political arguments escalated and it was eventually disbanded. Its successor, ESA, decided to learn from NASA and evolved systems management itself, just as JPL and others had in America years before.

Britain mishandled its involvement badly. It helped create ELDO as part of its desperate attempt to join the EEC. It ended up paying more than its share of the costs. It was then rapidly disillusioned and wanted to save money as its economy wobbled. It abandoned making missiles itself and decided to buy them from America, thus opting out of the technology development. This was part of a general Whitehall shift away from the idea of Britain leading in key technologies and towards simply buying things. This was disastrous economically, politically, culturally, and scientifically.

Systems management: results and legacy?

Missile reliability increased from about 50% in the early 1950s to 85-95%. The total engineering development effort for the the Atlas/Titan Project required about 31 million engineering man-years and took just over four years from 1955-9. In contrast, the B-52 bomber project required about 7 million engineering man-hours and took eight years.

JPL's record for space missions was near perfect for three decades. In July 1969, the Apollo mission successfully took men to the moon and returned them safely to earth. They managed to build spacecraft that could go around the moon and return to earth without any critical failures and a *failure rate for non-critical parts of just 1 part per million.*

Mueller and others had the next stages planned to capitalise on the success of Apollo by building substantial infrastructure in space for science and commerce including:

- a re-usable space plane to cut the cost per kilogram into orbit dramatically,
- a system of permanent space stations around the earth and moon serviced by inter-orbital transfer vehicles and lunar landing vehicles 'like a railroad in space' (thus also saving huge amounts of money because of not having to escape earth's gravity each trip),
- a permanent manned lunar base in the 1970s,

- a manned trip to Mars in the 1980s,
- and extensive scientific projects such as astronomy and remote sensing.[11]

These plans would also have involved big investments in computation and software which were a major roadblock for Apollo.[12]

Tragically, after the success in 1969 ambitions were curtailed, funding was slashed, and NASA itself forgot many of the lessons of Apollo's success. When the extreme focus and discipline brought by Mueller was relaxed, NASA slipped back to technical failure, repeated accidents, deaths, and wasteful budgets. It lost institutional memory and the culture that made it a success, as the reports on various disasters showed.

Part of the reason, according to Mueller himself, is that the successful systems management approach he used for Apollo which came from TRW had to be forced on NASA. *It did not grow there organically*. Once the lunar mission was achieved, the culture quite quickly dissolved: 'like most such structures, unless you have people that really understand why these things were done that way and what needs to be accomplished, it tends to drift into being form but losing its functionality' (Mueller). After the *Challenger* disaster, changes such as the 'faster, better, cheaper' reforms made many of the problems worse. The lack of integration got so bad that a $125 million Mars probe crashed because two teams did not realise that one of them was using imperial and the other metric units.

The budget process was never satisfactory. Apollo was funded adequately because the combination of Kennedy's goal and his assassination created a political imperative to continue with the project. The budget authorities in Washington however looked at the Apollo extension programme as just another thing to cut from to hit their annual targets so it was always under pressure. One of the strongest complaints from Mueller was the *lack of long-term budgeting* in Washington which focused on annual budgets and therefore imposed decisions which wasted money in the long-term.

It was very hard to keep Washington focused on what should come after the moon particularly as Vietnam went from bad to worse. Neither Nixon nor Congress would make the commitments of time and money to exploit Apollo's success properly. Nixon became so enraged with a lack of support from scientists over Vietnam that he stopped awarding the National Science Medal and disbanded the President's Science Advisory Committee. James Webb, NASA's overall boss, seems to have played an inglorious role. Hyper-political (not hyper-technical) Webb played the Washington game very astutely but he played a poor role in the aftermath of the fatal fire accident. He did not support the development of post-lunar plans as he could have done. Interestingly the scientific community, now so supportive of investment in space, was not in the 1950s and 1960s and they generally opposed many of Mueller's plans on the foolish assumption that if they stopped money going to space they might get some of it. Scientists have made the same mistake repeatedly in such budget/political battles.

Mueller later reflected:

> 'I was trying to get some payback for all of the work going into Apollo and bring it into the future. The astonishing thing to me was that no one was that interested in the future.'

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[11] Cf. '*The Post-Apollo Space Program: Directions for the Future: America's Next Decades in Space*', NASA 1969.

[12] By 2010 IBM's fastest *chip* was ~50,000 times faster than the whole Apollo computer complex.

In the dark days after the accidental fire that killed three astronauts he was sitting in a hotel room and wrote about the basic feeling among a sizeable group working on the project.

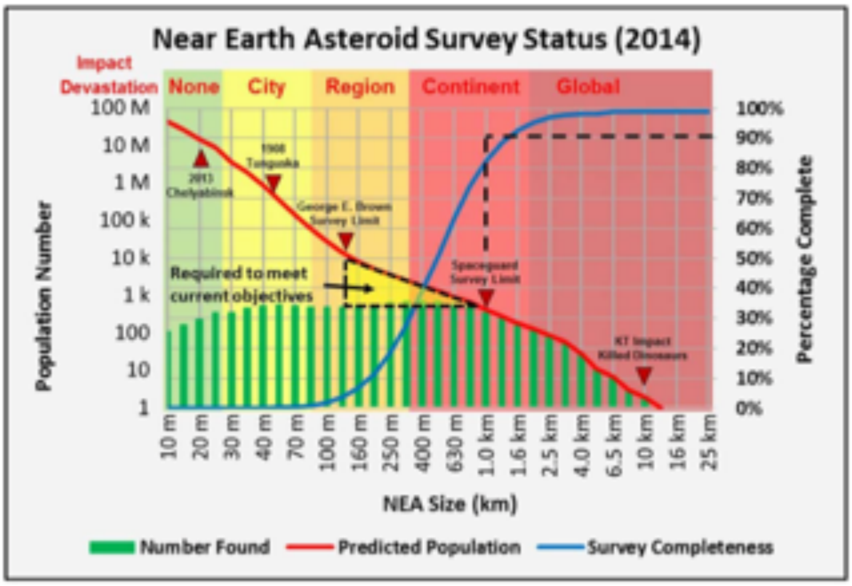
> '[T]o a remarkable extent the space program is founded on faith and on belief. On the faith that there is a future for mankind and on the belief that the future is one that will be good for all the people of the world both as individuals and as nations. On the faith that elsewhere in the universe life and intelligence exists and on the belief that finding and sharing knowledge and experience will be good for each race. On the faith that learning more about the stars and about the solar system will improve life here on Earth and on the belief that as man learns the secrets of space travel he will use these ships to explore and eventually inhabit other planets [and] tour the stars.'

Later he said:

> 'Men are going to live and work in space, and are going to explore and colonize the Moon as a stepping stone to establishing an outpost and then a colony on Mars… As we build this new civilization and become citizens of the solar system I believe we will be building a better life for all men and, at the same time, building the capability required for men to go to the stars.'

This unifying vision has been vindicated in many ways. Over the past decade, for example, we have begun to find thousands of planets, some of them potentially habitable and some orbiting the stars nearest to Earth. Many world-leading scientists have urged that building colonies in space is a vital insurance policy for humanity's survival.

We need insurance for many reasons. The most obvious is that we know for sure that either we implement enough of this grand vision for space such that we can manipulate the orbits of asteroids and other bodies or civilisation will be destroyed. There is no third way. In 1908 a ~50 metre diameter meteorite struck Siberia with an estimated impact of about 5-10 megatons of TNT which is ~500 times more powerful than the first nuclear bombs. Current estimates are there are over 300,000 such objects undetected. A ~140m object would have the power of about 60 megatons (more powerful than the biggest hydrogen bomb) and we have detected only about a quarter of the total estimated number of such objects. A ~1.5km diameter asteroid would have the force of ~500,000 megatons — over 30,000 times the size of the Hiroshima bomb. The object that is believed to have extinguished dinosaurs was about 10km and struck with the force of about 2 million 50 megaton hydrogen bombs. (Cf. Near-Earth Object Preparedness Strategy, US Gvt Jan 2017.)



A focused project to change the fundamental dynamics of international competition

Reviving the vision of Mueller and others is now partly in the hands of entrepreneurs like Amazon's Jeff Bezos and SpaceX's Elon Musk. If it were re-embraced by states including the UK, developing the solar system for commerce and science could give humanity *a joint endeavour that increases fundamental knowledge and demands new forms of international cooperation helping to suppress natural tendencies towards traditional international relations which will be fatal in the long run.*

Developing an *international manned lunar base* is logical as a first step in this vision providing a focused and achievable project within reasonable budgetary limits. It would require and promote fundamental improvements in autonomy, materials, and energy technologies. The rapid improvement in automation already underway would make this project significantly cheaper than was thought decades ago.[13]

It is also the case that Britain developed novel ideas about hypersonic space planes in classified programmes in the 1980s (SKYLON) that might also significantly reduce the cost per kilogram into orbit. This was closed down by Whitehall (ironically partly because of EU politics). Reaction Engines is developing a non-classified version of this technology but has been stymied by a Whitehall that is largely hostile to the idea of Britain developing major new technologies — it remains stuck in the 1970s mindset that we should just buy things from abroad.[14] Britain therefore potentially has very valuable technology to contribute to a manned lunar base project.

After the referendum Britain also needs new national priorities. Supporting a manned lunar base would kill two birds with one stone. First, it would give a huge boost to basic science and technological applications, requiring a civilian version of DARPA to improve a poorly functioning R&D and funding system. It would help make Britain a leading scientific power and help reverse the decline that is happening behind the scenes in cutting edge fields. Second, it would embed Britain in a project that would deliver real improvements in humanity's material circumstances and the dynamics of international competition/cooperation while the EU continues to ratchet itself into economic stagnation and political dysfunction and extremism.

Such ideas seem almost hopelessly naive with very low probability of success. People should keep in mind two things. First, many things regarded by conventional wisdom as very low probability happen when a relatively tiny number of able people decide to change something. Second, if we do *not* change course drastically, then the low probability of catastrophe in each particular year becomes a *near certain cumulative probability within a century*. Eventually our luck avoiding the near misses of 1962 (thanks Vasili Arkhipov), 1979, 1983, 1995 and so on must run out. Given the number of near-misses over the past 60 years how likely is it we will keep dodging them for another 100 years?

The scale of failure means the only rational attitude is to focus intelligent effort very tightly on changing the fundamentals of this problem. The referendum provides Britain a wonderful chance for a 'hard reboot' of failing institutions to the benefit of itself, Europe, and the wider world. John von Neumann's 1955 warning about the mismatch between science and political institutions seems even more prescient and frightening 60 years later but in one important respect we can escape his logic. He wrote (see above) that:

[13] Cf. Affordable, rapid bootstrapping of space industry and solar system civilization, NASA 2016.

[14] This mindset led Whitehall, *inter alia*, to destroy prototypes built by Barnes Wallis in XXX.

> '[L]iterally and figuratively, we are running out of room. At long last, we begin to feel the effects of the finite, actual size of the earth in a critical way.'

We do not have to remain within this limit. Breaking out of it is part of the solution to von Neumann's curse.

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Core lessons for politics?

'The astonishing thing to me was that no one was that interested in the future.' Mueller.

'The guy who's bringing reality into a pleasant party, and making people face their limitations and errors will have poor prospects.' Charlie Munger.

This story suggests some ideas about how to deal with our biggest problems.

1. It shows what is possible when large numbers of able people are unified around a compelling vision of significance for all humanity.

2. It shows a practical approach to implementing very large complex and difficult projects — the approach of systems management that can unify and integrate disparate expertise in ways that existing political institutions find generally impossible.

3. The parallel European effort shows that without the principles underlying systems management failure was constant.

4. It illustrates a recurring problem: even the rare organisations that do brilliantly on a hard problem struggle to maintain their culture once vital people leave (e.g. the German General Staff after the elder Moltke). Schriever was clearly a very unusual military officer, both in brains and willingness to risk his career. Mueller far more than Webb was responsible for Apollo's success. As soon as he left NASA began to slide and it has never fully recovered despite doing many wonderful things. Reading about Mueller suggests obvious connections with other very unusual and very successful people like Charlie Munger — a sort of 'no bullshit', steely focus on the job without concern for the normal things that divert people. Such people are probably +3 standard deviations (~1:1,000) on a handful of crucial dimensions (IQ, will power, management ability, metacognition etc) so the combination is very rare and, because of society's incentives, many of these people will not be working in a niche that optimises their rare talents. (How many +4SD intellects — global population ~250,000 — are also willing *and able* to navigate politics and bureaucracies as successfully as von Neumann?) It is also likely that intense efforts required to make things work brilliantly in hard conditions cannot be maintained for long without the feeling of crisis to motivate so there is a natural tendency to revert towards normal performance. We can see that even in the field of nuclear weapon safety, which on any rational basis ought to create a feeling of extreme crisis and therefore motivated effort, it has proved impossible to maintain high standards and embarrassing failures are common.

5. The development of projects such as ICBMs and Apollo had huge beneficial effects on the civilian economy. They fostered links between top scientists, engineers, companies, and universities. They provided funding for the development of large pools of expertise that had huge effects on the civilian high technology economy. They encouraged the development of hubs and the Silicon Valley hub in particular. By the end of the 1970s, elements of Soviet armed forces (notably Field Marshall Ogarkov) and the KGB realised that America had built a huge advantage in the computer and electronics industries that posed an existential threat to Communism which could not compete as it had in heavy engineering.

6. The whole effort, along with many other developments of great importance including the huge US investment in physics, maths, and engineering education and the creation of institutions such as DARPA, was motivated overwhelmingly by military competition — not a desire for learning per se. As soon as it seemed the Soviets could not compete, investment in these scientific projects declined. Is it possible to generate public and political support for such investments without fear of

severe military danger? Are we in the unfortunate position that only fear of China may motivate some useful investments?

7. Despite the success of the approach, inevitably the normal elements of the bureaucracy fought against its extension. Philip Morse, an MIT physicist who headed the Pentagon's Weapons Systems Evaluation Group after the war, reflected on this resistance:

> 'Administrators in general, even the high brass, have resigned themselves to letting the physical scientist putter around with odd ideas and carry out impractical experiments, as long as things experimented with are solutions or alloys or neutrons or cosmic rays. But when one or more start prying into the workings of his own smoothly running organization, asking him and others embarrassing questions not related to the problems he wants them to solve, then there's hell to pay.' (Morse, 'Operations Research, What is It?', Proceedings of the First Seminar in Operations Research, November 8–10, 1951.)

8. The flip side of this problem is the opposite problem most clearly represented by the hubris of McNamara's Whiz Kids and the Vietnam disaster: treating systems analysis and associated tools as capable of eliminating the fundamental issues of conflict such as complexity, the fog of war, passion and so on.

Although systems analysis and engineering first came from scientists and engineers, military officers and managers then used it to control *them*, then the Pentagon used it to control the whole R&D process. Configuration management, connecting engineering to costs and schedules, gave the managers the power of the purse.

> 'Just as scientific management enabled managers and engineers to coordinate and control factory workers in the first decades of the twentieth century, systems management enabled military officers and civilian managers to coordinate and control scientists and engineers… For systems management to remain stable over many years and projects, it had to have mechanisms for its constituent social groups to effectively interact. In the end, the primary mechanism became configuration management.' Johnson, p.211.

This was double-edged. At its worst it encouraged the McNamara 'whizz kids' delusion that war itself could be reduced to a systems management style approach. This hubris collapsed in Vietnam in predictable ways: for example, dodgy metrics like 'body counts' creating perverse incentives to distort action and reporting. War involves thinking opponents and is inherently different to physical engineering. As Colonel Boyd shouted, 'People, ideas, machines — in that order!'

9. It seems obvious to apply the systems approach to large complex social problems. This was tried including by Schriever himself who set up a company after leaving the army to do just that. He could not get it off the ground. In 1969 Simon Ramo wrote '*Cure for chaos: fresh solutions to social problems using the systems approach*'. TRW tried and became extremely frustrated with the delays, obstruction, and all the minor irritations of dealing with bureaucracies and normal branches of government. Without the focus provided by fear of the Soviets, it was extremely hard, usually impossible, to get governments and bureaucracies to adopt effective systems management. Proving that X works is not enough to get bureaucracies to accept X and change their own organisation. In the 1960s there was a wave of studies using the systems approach, riding the wave of Apollo, but the studies led to few clear successes. Strong reactions against Vietnam also strengthened anti-technology feeling and discredited the idea of learning from military projects.

Finally, I will summarise some of the core lessons of *systems management* that could be applied to re-engineering political institutions such as Downing Street. Mueller's approach meant an extreme focus on some core principles:

- Organisation-wide orientation. Everybody in a large organisation must understand as much about the goals and plans as possible. Whitehall now works on opposite principles: I doubt a single department has proper orientation across most of the organisation (few will have it even across the top 10 people), never mind a whole government. This is partly because most ministers fail at the first hurdle — developing coherent goals — so effective orientation is inherently impossible.

- Integration. There must be an overall approach in which the most important elements fit together, including in policy, management, and communications. Failures in complex projects, from renovating your house to designing a new welfare system, often occur at interfaces between parts. Whitehall now works on opposite principles: for example, Cameron and Osborne approached important policy on immigration/welfare in the opposite way by 1) promising to reduce immigration to less than 100,000 while simultaneously 2) having no legal tools to do this (and even worse promising to change this then failing in the EU renegotiation) and 3) having welfare policies that incentivised *more* immigration then 4) announcing a new living wage thus increasing incentives further for immigration. They emphasised each element as part of short-term political games and got themselves into a long-term inescapable mess.

- Extreme transparency and communication, horizontally as well as hierarchically. More, richer, deeper communication so that 'all of us understand what was going on throughout the program… [C]ommunications on a level that is free and easy and not constrained by the fact that you're the boss… [This was] the secret of the success of the program, because so many programs fail because everybody doesn't know what it is they are supposed to do' (Mueller). Break information and management silos — a denser network of information and commands is necessary and much of it must be decentralised and distributed between different teams, but with leadership having fast and clear information flow at the centre so problems are seen and tackled fast (a virtuous circle). There is very little that needs to be kept secret in government and different processes can easily be developed for that very small number of things. As McChrystal says of special forces operations generally the advantages of communication hugely outweigh the dangers of leaks. Whitehall now works on opposite principles: it keeps information secret that does not need to be secret in order to hide its own internal processes from scrutiny, thus adding to its own management failures and distrust (a vicious circle).

- 'Configuration management'. There must be a process whereby huge efforts go into the initial design of a complex system then there is a process whereby changes are made in a disciplined way such that a) interdependencies are tested where possible by relevant people before a change is agreed and b) then everybody relevant knows about the change. This ties together design, engineering, management, scheduling, cost, contracts, and allows the coordination of interdisciplinary teams. Test, learn, communicate results, change where needed, communicate… Whitehall now works on opposite principles: it does not put enough effort into the initial design then makes haphazard changes then fails to communicate changes effectively.

- Physical and information structures should reinforce open communication. From Mueller's NASA to JSOC, organisations that have coped well with complexity have built novel control centres to reinforce extreme communication. Spend money and time on new technologies and processes to help spread orientation and learning through the organisation. Whitehall now works on opposite principles: e.g. its antiquated committee structure and 'red box' system are ludicrously inefficient regarding management but are kept because they give officials huge control over ministers.

- Long-term budgets. Long-term budgets save money. Whitehall now works on opposite principles: normal government budget processes do not value speed and savings from doing things fast. They are focused on what Parliament thinks this year. This makes it very hard to plan wisely and wastes money in the long-term (see below).

- You need a complex mix of centralisation and decentralisation. While overall vision, goals, and strategy usually comes from the top, it is vital that extreme decentralisation dominates operationally so that decisions are fast and unbureaucratic. Information must be shared centrally and horizontally across the organisation — it is not either/or. Big complex projects must empower people throughout the network and cannot rely on issuing orders through a hierarchy. Whitehall now works on opposite principles: it is a centralising ratchet. E.g. Budgets and spending reviews are the exact opposite of Mueller's approach. 1) They are short-term with almost no long-term elements. 2) They do not balance off priorities in any serious way. 3) They involve totally fake numbers — every department lies to the Treasury and provides fake numbers. Treasury officials dig into these. There are rounds of these games. Officials never stop lying. To maintain the charade the Chancellor never says to the SoS 'stop your officials lying to us' — candour would break the system. 4) The Treasury does not have the expertise to evaluate most of what they are looking at. The idea it is a department staffed by brilliant whiz kids is a joke. I saw DfE officials with very modest abilities routinely cheat the Treasury.

- Extreme focus on errors. Schriever had 'Black Saturdays' and Mueller had similar meetings focused not on 'reporting progress' but making clear the problems. Simple as it sounds this is very unusual. Whitehall now works on opposite principles: routinely nobody is held responsible for errors and most management works on the basis of 'give me good news not bad news'. Neither the culture nor incentives focus effort on eliminating errors. *Most don't care and you see those responsible for disaster ambling to the tube at 4pm or going on holiday amid meltdown*.

- Spending on redundancy to improve resilience. Whitehall now works on opposite principles: it tends to treat redundancy as 'waste' and its short-term budget processes reinforce decisions that mean out-of-control long-term budgets. By the time the long-term happens, the responsible people have all moved on to better paid jobs and nobody is accountable.

- Important knowledge is discovered but then the innovation is standardised and codified so it can be easily learned and used by others. Whitehall now works on opposite principles: for example, in the Department for Education officials systematically destroyed its own library. The DfE operated with almost no institutional memory. By the time I left in 2014, after David Cameron banned me from entering any department officials would ask to meet me outside to find out why decisions had been taken in 2011 because three years later almost everybody had moved on to other things. The Foreign Office similarly destroyed its own library.

- Systems management means lots of process and documentation but at its best it is fluid and purposeful — it is not process for ass-covering. The crucial 'Gillette Procedures' swept away red tape and Schriever battled the system to maintain freedom from normal government processes. When asked how he would do a similar programme to Apollo now (1990s) Mueller responded that the only way to do it would be as a classified 'black' project to escape the law on issues like procurement. Whitehall now works on opposite principles: its obsession is bullshit process for buck-passing and it fights with all its might against simplification and focus.

- Saving time saves money. Schriever and Mueller focused on speed and saving time. Whitehall now works on opposite principles: its default mode is to go slower and those who advocate speed are denounced as reckless. Repeatedly in the DfE I was told it was 'impossible' to do things in the period I demanded — often less than half what senior officials wanted — yet we often achieved this and there was practically no example of failure that came because my time demands were inherently unreasonable. The system naturally pushes for the longest periods they can get away with to give themselves what they think of as a chance to beat 'expectations' but then they often fail on absurdly long timetables. In the DfE we often had a better record of hitting timetables that were 'impossibly' short than on those that were traditionally long. Also in many areas there is no downside to pushing fast — the worst that happens is minor and irrelevant embarrassment while the cumulative gains from trying to go fast are huge.

- The 'systems' approach is inherently interdisciplinary 'because its function is to integrate the specialized separate pieces of a complex of apparatus and people — the system — into a harmonious ensemble that optimally achieves the desired end' (Ramo). Whitehall now works on opposite principles: it is hopeless at assembling interdisciplinary teams and elevates legal advice over everything in relation to practically any problem, causing huge delays and cost overruns.

- The 'matrix management' system allowed coordination across different departments *and* different projects. Whitehall now works on opposite principles. It is stuck with antiquated departments, an antiquated Cabinet Office system, and antiquated project management. Anything 'cross-government' is an immediate clue to the savvy that it is doomed and rarely worth wasting time on. A 'matrix' approach could and should be applied to break existing hierarchies and speed everything up.

- People and ideas were more important than technology. Computers and other technologies can help but the main ideas came in the 1950s before personal computers. JSOC applied all sorts of technologies but Colonel Boyd's dictum holds: *people, ideas, technology — in that order.* Whitehall now works on opposite principles: for example, the former Cabinet Secretary, Gus O'Donnell, recently blamed a 'lack of investment' in IT and a shortage of staff for a huge range of Whitehall blunders. This is really deluded. The central problem is known to all experts and is shown in almost every inquiry: IT projects fail repeatedly in the same ways because of failures of *management*, not 'lack of investment', and adding people to flawed projects is not a solution.

Ministers have little grip of departments and little power to change their direction. They can't hire or fire and they can't set incentives. They are almost never in a job long enough to acquire much useful knowledge and they almost never have the sort of management skills that provide alternative value to specific knowledge. They have little chance to change anything and officials ensure this little chance becomes almost no chance.

This story shows how to do things much better than normal. It shows that the principles underlying Mueller's success are naturally in extreme competition with the principles of management that dominate all normal bureaucracies, public or private. People have been able to read about these principles for decades yet today in Whitehall almost everything runs on exactly the opposite principles: incentives operate to suppress learning. The institutional and policy changes inherent in leaving the EU are a systems problem requiring a systems response. Implementing Mueller's principles would mean changes to most of the antiquated and failing foundations of Whitehall and bring big improvements and cost savings. Such changes are likely to be resisted by most MPs as well as Whitehall given few of them understand or have experience in high performance teams and would regard Mueller's approach as a threat to their career prospects.

Because Whitehall is a *system failure* in which different failures are entangled, its inhabitants tend to potter around in an uncomprehending fog of confusion without understanding why things fail every day and therefore they do not support changes that could improve things *even though these changes would be personally advantageous particularly for the first mover.*

What is the minimum needed to break bureaucratic resistance and spark a virtuous circle?

How can people outside the system affect mission critical political institutions protected from market competition and resistant to major reforms?

How can we replace many traditional centralised bureaucracies with institutions that mimic successful biological systems such as the immune system that a) use *distributed information processing* to identify useful structure in the environment, b) find 'good enough' solutions in a vast search space of possibilities, and c) move at least ten times faster than existing systems?

Please leave comments or email dmc2.cummings@gmail.com

Some further reading

Can we survive technology?, von Neumann, 1955.

The Apollo Tradition: An Object Lesson for the Management of Large-Scale Technological Endeavors, Seamans and Ordway (NASA administrators), 1977.

The development of ballistic missiles in the US Air Force, Neufeld, 1990.

Inside NASA, McCurdy, 1993.

Secret of Apollo, Johnson.

Systems, experts, and computers, edited by Hughes.

Doing the Impossible, Slotkin, 2012.

A fiery peace in a Cold War, Sheehan, 2009.

Rescuing Prometheus, Hughes.

Team of Teams, Stanley McChrystal.

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