How I learned to stop worrying and love the Bombe: Machine Research and Development and Bletchley Park

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Mechanising the Information War – Machine Research and Development and Bletchley Park

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Abstract

The Bombe machine was a key device in the cryptanalysis of the ciphers created by the machine system widely employed by the Axis powers during the Second World War – Enigma. The Bombe machine was initially designed Britain by scientists in primary cryptanalysis agency, the Government Code and Cypher School at Bletchley Park. The machines were then mass produced by the British Tabulating Machine Company in Britain, and by the National Cash Register Company in the United States of America. The design, development and mass production of the machine was a fraught process dependent on support from scientists and bureaucrats within the agency, but more importantly the agency was only moved to mechanise, and subsequently professionalise, this key function in its operations when met with a series of major crises. The result was an unplanned *ad hoc* process of designing, building and operating the machines. This was representative of the wider process of mechanisation within Bletchley Park, one of the most important and renowned technological centres to emerge in Britain during the Second World War.

Key Words: Bletchley Park, Bombe, Mechanisation, Enigma, Cryptanalysis, Intelligence.

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In time of peace there is little stimulus to invent equipment for which there is no general demand. … governments are by habit content with what they have, unless some major crisis forces them to pay closer attention to security and speed.[1]

- The Internal History of British Security Coordination (1945)

During the Second World War Bletchley Park, the primary war station of the Government Code and Cypher School (GC&CS), was a hive of activity. Each month tens of thousands of enciphered Axis wireless messages were intercepted by Britain's wireless interception service – the Y Service. For instance, in November 1942 approximately 40,000 messages were intercepted in the United Kingdom.[2] These messages arrived at Bletchley Park for deciphering, translation and sorting. Useful intelligence was distributed to appropriate Ministries and military commands. In order to deal with this volume of traffic Bletchley Park constantly expanded, increasing in staff numbers until the final months of the war, adding new sections to its operational apparatus, and overseeing the expansion of existing sections. The agency also adopted new methods of approaching its work and administration; mechanising many of its key processes by installing ingenious new technologies, often custom designed, built and adapted, which offered automated

1 Nigel West (ed.), *British Security Coordination: The Secret History of British Intelligence in the Americas 1940-45* (London, 1998) 454-455

2 Johnson, Kerry and Gallehawk, John (eds.), *Figuring it Out at Bletchley Park: 1939-1945* (Redditch, 2007), 170.

solutions to the increasingly complex and increasingly ubiquitous mechanical cipher systems employed by the Axis powers.

This article examines one aspect of the mechanisation of GC&CS, the partial mechanisation of the cryptanalysis of messages enciphered by the famous Enigma cipher machines.[3] It seeks to examine how the administrative and organisational structures within GC&CS reacted and adapted to meet the changing pressures of an increasingly mechanised "information war". The article also considers why the agency developed in the manner in which did. GC&CS was, from its inception in 1919, an increasingly professional organisation, which sought out and recruited specialists in linguistics, history, classics, and other literary disciplines and later mathematics, physics and business administration; a clear shift in direction from the arts to the sciences. The historian Jon Agar sees the rise of scientists and technocratic specialists, within Civil Service as a

3 Other aspects of GC&CS's mechanisation have been explored elsewhere, for instance the massive mechanical data storage system, comprised of hundreds of thousands of punch cards, has been examined in some detail by Rodney Brunt. Similarly, the collaboration between British Security Co-ordination and GC&CS, to develop Britain's primary wartime machine cipher system, Typex has been explored by John Ferris. Ferris also discusses the development of the Rockex II cipher system - an important electronic machine cipher system developed during the war and utilised in the early years of the Cold War. Rodney Brunt, 'Indexes at the Government Code and Cypher School, Bletchley Park, 1940-1945', in Boyd W. Rayward and Mary Ellen Bowden (eds.), *The History and Heritage of Scientific and Technological Information Systems: proceedings of the 2002 conference of the American Society for Information Science and Technology* (Medford: NJ, 2004) 291-299; John Ferris, *Intelligence and Strategy: Selected Essays* (London, 2005), 138-180.

whole, as a key driving force of mechanisation and bureaucratic professionalisation within Britain's structures of governance, citing Bletchley Park as an example.[4] This article builds on that interpretation, suggesting that while technocratic specialists within Bletchley Park facilitated mechanisation, the agency was partly, in fact, resistant to changing the existing structures and sometimes hostile to new technologies, and that mechanisation owed as much to wartime tests[5] and opportunities as it did to the professionalising influence of scientists. The agency can be broadly, though as will be shown there was considerable overlap, split into two different camps: those cryptanalysts from an earlier generation, typically academics drawn from the arts faculties who approached the problem of codebreaking through an examination of language and linguistics; and a later generation of mathematicians, scientists and managers who were arguably more open to new techniques, including mechanisation.

Specifically, change only occurred in response to overwhelming external and internal logistical and political pressures. The result was that mechanisation and professionalisation occurred in a haphazard and *ad hoc* fashion, because the agency was typically resistant to and, given the weight and rapid emergence of problems, incapable of

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4 Jon Agar, *The Government Machine: A Revolutionary History of the Computer* (Cambridge: MA, 2003).

5 A theme discussed in the context of wartime social and cultural change, see Arthur Marwick, *Britain in the Century of Total War: war, peace and social change, 1900-1967* (London, 1968).

long-term planning. In order to illustrate this unplanned and *ad hoc* process of institutional evolution, this article will draw upon the development of the Bombe. The Bombe machines were complex pieces of apparatus designed to aid in the cryptanalysis of the famous Enigma cipher system.

Unsurprisingly, given the significance of wartime cryptanalysis to Allied prosecution of the war, there has been significant study of the work of GC&CS. The majority of this literature has been dedicated to the question of what influence Allied signals intelligence had upon the outcome of the Second World War. This trend was set by the very first full length English language book to be written on the subject; the memoir of the intelligence officer F. W. Winterbotham.[6] Subsequent memoirs and histories largely continued with the same focus.[7] It was not until the publication of the memoir of the cryptanalyst Gordon Welchman in 1986, that some of the questions regarding the technical methods employed to break Axis ciphers began to be addressed. Interestingly, Welchman, who was also a senior manager at Bletchley Park, also gave some insight into the evolving bureaucracy at Bletchley Park and how the structure of the agency facilitated the work of the cryptanalysts. Importantly, Welchman also provided his recollections of the construction

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6 F. W. Winterbotham, *The Ultra Secret: The Inside Story of Operation Ultra, Bletchley Park and Enigma* (London, 1974, 2000).

7 For examples see: Peter Calvocoressi, *Top Secret Ultra: the Full Story of Ultra and its Impact on World War II* (London, 1981); Ewen Montagu, *Beyond Top Secret U* (London, 1977); Ronald Lewin, *Ultra Goes to War: The Secret Story* (London, 1978, 1980); Hinsley, F. H., Thomas, E. E., Ransom, C. F. G., and Knight, R. C., *British Intelligence in the Second World War*, 5 vols. (London, 1979-1990).

of the Bombe machines. Relatively recent studies of Bletchley Park and GC&CS have expanded our understanding of the agencies structures,[8] and the technical specifications of its machines,[9] but very little has been said regarding the actual process of constructing the machines, those who advocated building them, and the extent to which opposition impeded and delayed construction. No study has attempted to map the influence of social and cultural developments within the agency and the process of mechanisation by the agency. Filling this gap yields an interesting story in of itself, but more importantly it also serves as a vehicle to test various theses within the field of wartime science and technology, which most certainly have considered the influence of wider society and culture in the development of technology.

Relatively recent work regarding the attitude of the British state towards scientific and technological development in wartime has produced interesting, if conflicting studies. David Edgerton, for instance, has argued that the British state was militant, scientific and technocratic, and that the importance of mechanised warfare and industry was encouraged from the highest levels of government. For instance, Edgerton argues that the Civil Service, and government, rather than being dominated by men with an education in the classics, who did not understand science, and who were resistant to new technology, in

8 Stephen Budiansky, *Battle of Wits: The complete story of codebreaking in World War II* (London, 2000, 2001); R. A. Ratcliff, *Delusions of Intelligence: Enigma, Ultra and the End of Secure Ciphers* (Cambridge, 2005).

9 Paul Gannon, *Colossus: Bletchley Park's Greatest Secret* (London, 2007); B. Jack Copeland, *Colossus: The Secrets of Bletchley Park's Codebreaking Computers* (Cambridge, 2010).

fact, contained a powerful core of scientifically educated technocrats. Moreover, Edgerton argues that the British state was, in fact, highly technologically advanced by the standards of the day, militaristic, and far better prepared for war than often assumed. Moreover, the centrality of science and technology was championed from the highest levels of Britain's wartime government.[10]

Thus, Edgerton writes, "Wartime Britain saw a quite extraordinary cult of invention and inventor, whose high priest was the Prime Minister himself.[11] Gadget factories of all sorts flourished under his leadership, driving others to exasperation."[12] Moreover, the receptive authorities were not resistant to new technologies, but found themselves in the position of "choosing between any number of novel machines."[13] Importantly, Edgerton's emphasis

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10 Edgerton, *Britain's War Machine*: *Weapons, Resources and Experts in the Second World War* (London, 2012).

11 Evidently Churchill's own education was no bar to his belief in the power of scientists to provide solutions to Britain's military problems. He was educated at several independent schools prior to attended Harrow School and later the Royal Military College, Sandhurst. According to Henry Pelling's biography of Churchill, the future Prime Minister's Latin was poor and his grasp of mathematics and French mediocre. He failed his first attempt to pass the Sandhurst entrance exam, and, even following an intensive 'crammer' course, was unable to qualify for the infantry and initially made do with the cavalry and its less exacting entry standards. Henry Pelling, *Winston Churchill* (Ware, 1977), 32-37.

12 Edgerton, *op. cit.* (ref. 6), 234.

13 Edgerton, *op. cit.* (ref. 6), 235.

on Churchill, and other senior figures within Britain's wartime establishment, is suggestive of a receptiveness to technology driven from above, granting scientifically and technologically minded individuals a considerable amount of leeway and resources to arm Britain's military services, mechanise her apparatus of state, and modernise her industry.

Jon Agar, in his history of the British Civil Service, argues that the government is like a machine.[14] That the manner in which the government, and Civil Service departments, operate employ machine-like processes, and that senior members of the Civil Service, deliberately characterised the bureaucracy of state in these terms. The purpose being to generate trust in the Civil Service; machines are impartial, efficient, and, of course, "mechanical" in their operation. Furthermore, the "government machine" also operated a policy of the physical, as opposed to metaphorical, mechanisation of its processes during the nineteenth and twentieth centuries. Thus the Civil Service, already operating like a machine and encouraging that view of itself, began the process of mechanising its work. This process of mechanisation, Agar argues, was spearheaded by an increasingly influential middle-ranking tier of technocratic specialists within the Civil Service and, in particular, the Treasury. This technocratic group was comprised of scientific specialists who persuaded their more senior colleagues, the Civil Service mandarins often with an education in the classics as opposed to the sciences, to adopt their policy of

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14 Agar, *op. cit.* (ref. 5). Of course, Agar is not alone in examining organisations and bureaucracies as machines. The metaphor has been discussed and considered in the context of organization theory. See, Morgan, *Images of Organization* (Thousand Oaks: CA, 1984, 2005), 369-374.

mechanisation, which the mandarins agreed to on the basis that it would make work more efficient and less costly. Thus, the mechanisation of government was directed and driven from within, by a group of powerful technologically minded specialists.

One of the key case studies deployed by Agar in his analysis of the growth of mechanisation in government is Bletchley Park. Agar argues that over the course of the war GC&CS had "transformed from a collegiate to an industrialised bureaucracy: an organization marked by an intricate division of labour, very high staff numbers, an emphasis on through-put, and innovative mechanization at bottlenecks, all directed to speeding up and making more efficient processes of manipulating symbols."[15] Agar's model is a useful one to consider within the context of this discussion of the development of GC&CS's administration and its process of mechanisation, however it is not without problems. Like Agar, Alan Turing's biographer, Alan Hodges also considered the professionalization of GC&CS. Hodges pointed to the arrival of mathematicians as having a professionalising and transformative influence on the agency.[16] This conclusion is, however, problematic, because, contrary to the common assumption that GC&CS began recruiting mathematicians in the months immediately prior to war, the agency had in fact, been recruiting a small number of mathematicians since the early 1930s at the very latest.[17] This begs the question of why the transformative, mechanising and

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Agar, *op. cit.* (ref. 5), 414.

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Andrew Hodges, *Alan Turing: the Enigma* (New York, 1992), 549.

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professionalising impact of mathematicians had not occurred during the interwar years? Of course, number of mathematicians employed by GC&CS increased rapidly during the war, and particular mathematicians, like Alan Turing and Gordon Welchman both of whom played a major role in the development of the Bombe machine, were recruited in 1939. It is undeniable that both men played a major role in facilitating and championing the mechanisation of GC&CS; however, it is clear that the arrival of scientists alone could not facilitate mechanisation which did not occur until wartime.

The organization theorist Christopher Grey, rather than proposing a linear development within GC&CS, highlights the importance of the type of working being conducted and the autonomy of workers. Thus, while areas of work deemed to be "low skilled", such as machine operation, took on the characteristics outlined by Agar, "highly skilled" sections, such as that of cryptanalysts and translators retained many of the characteristics of collegiate system of the pre-war agency. Grey presents an image of GC&CS's different sections, run on different principles as described above, being "twisted together" over the course of the war.[18] Grey's model is useful as it highlights the often *ad hoc* of GC&CS's growth, professional and mechanical in some areas of its work, but unorthodox, unregimented and, perhaps, even anarchic in others particularly those areas deemed to require leeway to lubricate the wheels of creative and intellectual expertise. As we shall

Alistair Denniston to C. E. D. Peters, 26 April, 1932, HW 72/9, TNA.

18

Christopher Grey, *Decoding Organization: Bletchley Park, Codebreaking and Organization Studies* (Cambridge 2012), 213-240.

see, this freedom and attitude within GC&CS was provided in abundance to GC&CS's technical experts and had a considerable impact upon the development of the Bombe machine and later adapted models. However, Grey's model is incomplete and applies primarily to the development of GC&CS's organisational structure. The impact of these developments on, or even whether they apply at all to, the process of mechanisation within GC&CS is all but omitted. Thus, while Grey's model is useful in understanding GC&CS's overall organisational development, further thought is needed in understanding the process of cryptanalytic mechanisation during the war.

The majority of the historiography discussed thus far has revolved around relatively recent studies. Of course, historians have long been interested with the relationship between the state, state institutions, and science and technology. In the period before 1990s, in particular during the 1970s and 1980s, a number of historians, observing the relative waning of Britain as a first-rate military and industrial power, sought to explain and understand this apparent "decline" during the late nineteenth and twentieth centuries.[19] Part of this decline, they argue, was a result of British industry and the government's failure to appreciate and adopt new technologies. Indeed, Barnett argued

[19] For instance see Correlli Barnett's trilogy on the subject. Correlli Barnett, *The Collapse of British Power* (London, 1972); Correlli Barnett, *The Audit of War: The Illusion and Reality of Britain as a Great Nation* (London, 1987); Correlli Barnett, *The Lost Victory: British Dreams, British Realities, 1945-1950* (London, 1995). For other examples, see Martin J. Weiner, *English Culture and the Decline of the Industrial Spirit, 1850-1980* (Cambridge, 1981); Michael Dintenfass, *The Decline of Industrial Britain: 1870-1980* (London, 1992).

that, during this period, politicians and civil servants were actively resistant to emergent technology. Barnett, looking back to the mid-nineteenth century, suggests that the root of this technological ignorance was to be found in the education of Britain's elite – the public school system, from which senior civil servants were drawn. The Civil Service was, in Barnett's estimation, filled with men who had been recruited from Britain's elite public school system and universities, Oxbridge in particular. These establishments placed an emphasis on a classical education, with particular emphasis on Greek and Roman, with lesser attention and status paid to modern subjects, such as history and modern European languages. Mathematics, physics and chemistry, were largely omitted from their curricula. Where science was admitted, it was of a low level.[20] The result was that the brightest boys left school, and in turn Oxford and Cambridge Universities, with a particular set of skills and education that excluded, and undervalued the sciences. Thus, "British educational neglect in the nineteenth century artificially created a stupid, lethargic, unambitious, enterprising people for the twentieth century. The consequences were insidiously to affect many fields of national performance."[21] Thus, the educated elite, many of whom joined the ranks of the Civil Service, had little education in, or understanding of, science and technology. This, in Barnett's view, led to stagnation in terms of technological foresight within government and hostility towards technological change. The result was that "[T]he values and world view of this British governing class

20 Correlli Barnett, *The Collapse of British Power* (London, 1972), 31.

21 Barnett, *op. cit.* (ref. 20), 105.

were thus profoundly pre-industrial, conservative, nostalgic."[22] Furthermore, "the governing class's whole ethos and conditioning made it static in outlook rather than dynamic, seeking continuity before change."[23]

Thus, in the minds of those historians who see Britain as having entered a period of decline, there was an absence of sponsorship of scientific and technological development in Britain during the late 19th century and into the 20th century. In no small part this was, they suggest, a result of a failure of the upper-echelons of Government and the civil service to appreciate the merit and potential of investing in scientific and technological projects. Of course, this thesis stands in direct contrast to later historical research, conducted by the likes of David Edgerton, who argued the precise opposite. Meanwhile, as noted, Jon Agar observes a powerful and technocratic group of specialists within the civil service who actively mechanised the service from within. It is clear from this research that, contrary to the declinist thesis, that the British government was not hostile towards technological advances, and certainly not during the Second World War.[24]

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22 Correlli Barnett, *The Audit of War: The Illusion and Reality of Britain as a Great Nation* (London, 1987), 221.

23 Barnett, *op. cit.* (ref. 22), 221.

24 For instance see: Jose Harris, 'Enterprise and Welfare State: A Comparative Perspective', *Transactions of the Royal Historical Society*, Fifth Series, 40 (1990), 175-195; Jim Tomlinson, 'Correlli Barnett's History: the Case of the Marshall Aid', *Twentieth Century British History*, 8, no. 2 (1997), 222-238; David Edgerton, *Warfare State: Britain, 1920-1970* (Cambridge, 2005).

Technological solutions to complex problems, such as the Bombe machine as a response to mechanised cryptography, were certainly embraced by the British government and, as this article will show, substantial funding and manpower was provided to the project of mechanising cryptanalysis.

Clearly then, the 'declinist' thesis has only limited utility in examining the construction of the Bombe machines; not only was GC&CS, as an agency, able to draw upon significant resources and support from the British state, but it was able to channel those resources into the development of novel technologies designed by professional scientists. However, it is certainly the case that the senior figures within GC&CS, who were drawn from an 'old guard' of GC&CS recruit and often reflected the educational background of Barnett's caricature civil servant, were often the most apathetic when it came to adopting new methods and technologies. As a result, the explanation that because Britain was a technocratic militant state, it naturally followed that its scientific military institutions would be at the forefront of mechanisation requires further nuance. Meanwhile, Agar's conclusion that mechanisation occurred because of the arrival of scientific mechanisers, with a technocratic ideology, also fails to fully encapsulate the process of mechanisation. Rather than embracing technocratic solutions, such as the Bombe machine, Bletchley Park's senior staff members, were, in fact, typically indifferent and prone to technological inertia; building machines, upgrading them, and efficiently utilising them, only when existing measures were stretched to breaking point. Instead, the agency invariably took the line of least resistance, adopting mechanisation only when all else failed, resulting in a distinctly *ad hoc* and unplanned process of mechanisation, achieved only in fits and starts, which only occurred at moments of major institutional stress brought about by the wider pressures of war.

To understand the process of mechanisation at Bletchley Park, it is necessary to examine how the GC&CS's senior staff and government sponsors were forced to reconsider their attitudes towards technology and the role of machines, and how wartime developments created opportunities for Bletchley's scientists .

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Britain's cryptanalysis services began the interwar period with a clearly defined emphasis on academia. Academics, particularly those scholars who specialised in classics, languages and history, had, during the First World War proven ideal candidates to solve the problem of cryptography. They were well educated, understood the mechanics of language and communication, and were professionally engaged in the work of teasing meaning from complex, alien and damaged sources of information.[25] They also brought with them the collegiate, and often anarchic, culture of the universities from which they had been drawn and, particularly in the case of Dillwyn Knox (perhaps the greatest cryptanalyst of GC&CS's "Old Guard") complained bitterly when the agency attempted to professionalise and compartmentalise their work.[26] Furthermore, during the Second World War the manner in which GC&CS operated did indeed change. While the sections housing the cryptanalysts and linguists remained forever tied to the university common rooms from which many of the senior staff had been drawn, many of the new sections to

25 Mavis Batey, *Dilly: The Man Who Broke Enigmas* (London, 2009), 20.

26 Michael Smith, *Station X: The Codebreakers of Bletchley Park* (London, 2004), 126.

emerge within GC&CS were very different. These sections were the natural by-product of the mechanisation of cryptography and the increasing ubiquity of wireless communication. Dealing with the new technologies being deployed by the Axis powers required necessitated a mechanical response in the fields of cryptanalysis, data storage and manipulation, communication, and general administration. Each of these newly mechanised functions of the agency required new sections and an increasingly large pool of staff members. This was all precipitated by the development of the Enigma cipher machine.

A commercial model of the Enigma machine, designed by the German electrical Engineer Arthur Scherbius, first entered the market in the early 1920s. It was not the first machine cipher system to have been patented or marketed, and for the first few years the machine failed to find the market that Scherbius had hoped for. However, in 1926 the German Navy adopted a modified variant of the system, and by the outbreak of war in 1939 various different Enigma systems had become ubiquitous throughout the German state and military agencies.

The Enigma machine resembled a typewriter. The purpose of the machine was to allow an operator to press a key on the machines keyboard and generate a different letter seemingly at random. The machine worked by creating an electrical signal, each time a key was depressed, which would light a corresponding letter on a lamp board located above the keyboard. Between the keys and the lamps, lay a series of three rotors, each with 26 potential positions representing letters of the alphabet, and each rotor position creating a different electrical pathway. The machine also included a reflector, so once the electrical signal had passed through the machine, it would be returned back through the rotors and thus through an entirely different pathway. The German military Enigma machines also included a *Steckerverbindungen*, a plug board, allowing the operator to manually plug a letter to a different corresponding lamp, adding an extra layer of complexity.[27] Moreover, each time a key was depressed one or more rotors would move forward a position, thus the same key could be depressed multiple times and each occasion lighting a different corresponding letter. Unless the recipient of a message knew the precise configuration of the machine, or "key", which had generated the message all the reader would have was a meaningless series of letters.

For its day, the machine offered considerable advantages. It was easily mass-produced, it was relatively small and light making it portable, and it offered a high degree of security. To make matters more complex, it was also relatively easily modified, and various branches of the German state adopted their own customised version or variant of the Enigma system. Thus, these variants of Enigma were typically unique to the agency which had adopted them, heavily upgraded and generally deemed by the agencies in question to be unbreakable[28] – according to the internal history of GC&CS commissioned at the end of the war, this was also a view shared by Britain's cryptanalysts in during the

27 Marian Rejewski, 'Mathematical Solution of the Enigma Cipher', trans. Christopher Kasparek, *Cryptologia*, 6, no. 1 (1982): 1-18, 2.

28 Ratcliff, *op. cit.* (ref. 8), 4-23.

latter part of the interwar period.[29] GC&CS's cryptanalysts concluded that if Enigma messages were to be read, and read on a suitably regular and swift basis to derive any useful intelligence, the agency might need to develop an "elaborate apparatus which had not yet been designed."[30] In other words, the mechanical revolution in cipher technology would require a similar mechanical revolution in the profession of cryptanalysis.

The British were not alone in that assessment, the Polish Cipher Bureau had come to the same conclusion and by 1938 had developed a mechanical device they called the *Bomba*. With this device the Poles enjoyed some success against some of the German military Enigma systems at least until July 1939 when the Germans upgraded their systems.[31] However, aside from speculation, it was not until the British learned of the Polish successes that serious consideration was given to mechanical aids in tacking the Enigma problem. Indeed, comparatively little consideration had been given to Enigma at all up until that point.

29 Frank Birch, *The Official History of Sigint*, vol. 1 (part 1), John Jackson (ed.) (Milton Keynes, 2004), 20. This volume, in addition to its counterpart, vol. 1 (part 2) & vol. 2, John Jackson (ed.) (Milton Keynes, 2007), is a published reproduction of an internal history of GC&CS held at the National Archives, Kew (TNA). Frank Birch, 'History of British Sigint, 1914-1945', HW 43/1-2, TNA.

30 Birch, *The Official History of Sigint*, vol. 1 (part 1), 20.

31 Birch, *The Official History of Sigint*, vol. 1 (part 1), 20.

In retrospect, given that the Enigma system had been adopted by elements of the German military as early as 1926 and by the mid-1930s was becoming increasingly ubiquitous it is surprising that GC&CS did not employ its resources on the problem until the late 1930s. As Birch noted, "it was not until May 1938 that, in naval Section GC&CS, a German subsection, consisting of one officer and one lady clerk, neither of them a cryptanalyst, was set up to analyse the traffic."[32] The cause of this limited attention to the problem was two-fold, firstly GC&CS was preoccupied with the problems posed by Imperial Japan and fascist Italy, and secondly because the Enigma system was advanced beyond the capabilities of GC&CS to tackle at that time. [33] Such was the pessimism within GC&CS, particularly when it came to the most challenging variant of the German Enigma systems, that of the German Navy, was widely believed to be unbreakable. There were only two individuals who took exception to this otherwise ubiquitous belief; these were Frank Birch and Alan Turing. According to the cryptanalyst Hugh Alexander, latterly the commander of Hut 8, the GC&CS section tasked with the campaign against the ciphers employed by the German Navy, the reasons they differed from the rest of GC&CS were two-fold.

> Birch thought it could be broken because it had to be broken and Turing thought it could be broken because it would be so interesting to break it. Whether or not these reasons were logically satisfactory they imbued those who held them with a determination that the problem should be solved and it is to the pertinacity and

[32] Birch, *The Official History of Sigint*, vol. 1 (part 1), 19.

[33] Birch, *The Official History of Sigint*, vol. 1 (part 1), 20.

force that, in utterly different ways, both of them showed that success was ultimately due.[34]

Giving a further insight into Turing's attitude, A. P. Mahon, a fellow Bletchley Park staff member, recorded in the internal history of Hut 8 written in 1945, that "When Turing joined the organization in 1939 no work was being done on Naval Enigma and he himself became interested in it 'because no one else was doing anything about it and I could have it to myself'."[35]

The result was that GC&CS came late to attack the problem of Enigma, and still later to the development of a machine with the Enigma problem in mind. It was not until after the war had begun, in October 1939 that development of the Bombe began and May 1940 that the first prototype Bombe machine was delivered to Bletchley Park.[36] The machines themselves were large electro-mechanical devices designed to help cryptanalysts discover the rotor positions of the Enigma machines. The Bombe effectively consisted of a series

34 C.H.O'D. Alexander, *Cryptographic history of work on the German Naval Enigma* (no date, c. 1945), HW 25/1, The National Archives, Kew (TNA). This document was accessed online courtesy of Graham Ellsbury, http://www.ellsbury.com/gne/gne-000.htm (accessed: 25 June 2013).

35 AP. Mahon, *The History of Hut Eight 1939 – 1945*, HW 25/2, TNA, 14. This document was accessed online courtesy of Graham Ellsbury, http://www.ellsbury.com/hut8/hut8-000.htm (accessed: 25 June 2013).

36 Birch, *The Official History of Sigint*, vol. 1 (part 1), 41.

of three rows of 36 rotating drums, the drums replicating the function of an Enigma machine. These drums, as well as vast quantities of internal wiring, were housed in a large bronze cabinet over six feet in height, seven feet in width and two feet in depth.

Part of the problem with the development of such technologies was that the machines were extremely expensive by the standard of the day. For instance, the project to design and development of the Bombe machines was granted a budget of £100,000.[37] This led to considerable opposition from within the agency for the design and construction of the machines. As Mahon explained,

> Unfortunately the Bombe was an expensive apparatus and it was far from certain that it would work or, even if the Bombe itself worked, that it would enable us to break Enigma. Its original production, and above all the acceptance of a scheme for large scale production, was the subject of long and bitter battles and Hut 8, and of course, Hut 6, owe very much to Commander Travis and to a lesser extent to Mr. Birch, for the energy and courage with which they sponsored its production.[38]

Of course, neither Birch nor Travis were technocratic expert mechanisers. Both of them were products of an earlier cryptanalytic era, the First World War with its emphasis on classics and language as opposed to mathematics and engineering, and resultantly neither

37 Smith, *op. cit.* (ref. 20), 60.

38 Mahon, *The History of Hut Eight 1939 – 1945*, HW 25/2, TNA. 28.

were trained mathematicians and scientists. As noted, Birch was an historian by trade, while Travis had been recruited into cryptanalytic work from the ranks of Royal Navy.[39] They looked to mechanical solutions to the Enigma problem, as Alexander noted of Birch, "because it had to be broken". The issue was one of necessity dictated by the escalating problems posed by the war, primarily that Britain's chief opposing power, Nazi Germany, had adopted a machine cipher system that could not be quickly broken without mechanical aids.

The arrival of mechanical solutions, to speed up the process of cryptanalysis, in 1940 heralded a new chapter in British cryptanalysis, and the almost lackadaisical attitude towards the problems posed by machine ciphers had come to a definite end. The evolution in British cryptanalysis heralded by the development of these machines, was certainly quickly appreciated by the cryptanalysts. The arrival of the prototype in April 1940 was followed, in August, by an improved model. By the summer of 1941, the Bombes were deemed to have proven their worth and production had begun in earnest.[40] By the end of the war in Europe some 200 machines had been built.[41]

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39 D. R. Nicoll, 'Travis, Sir Edward Wilfrid Harry (1888–1956)', in *Oxford Dictionary of National Biography* (Oxford, 2004).

40 Mahon, *The History of Hut Eight 1939 – 1945*, HW 25/2, TNA, 29.

41 John Keen, *Harold 'Doc' Keen and the Bletchley Park Bombe – Code name CANTAB*, 2nd ed., (Kidderminster, 2012), 39-43.

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However, all was not smooth sailing. The machines, throughout 1940 and 1941 existed only in minimal numbers. By August 1941 still only six machines were available.[42] This led to considerable bottlenecks as demand from the two main sections dealing with Enigma traffic, the German Naval cryptanalysis section in Hut 8 and the Army and Air section in Hut 6, both required machines. This led to various complaints being made regarding the allocation of the machines and more general disquiet regarding the slow rate at which machines were delivered. As Birch noted in a letter to Travis in August 1940, “Turing has stated categorically that with 10 machines he could be sure of breaking Enigma and keeping it broken. Well can't we have 10 machines?”[43]

The cause of these delays was partly because it took considerable time and expertise to build the complex machines. To provide an idea of the complexity, it is worth noting that each machine contained approximately a million soldered connections and ten miles of wire.[44] GC&CS had contracted the British Tabulating Machine Company (BTM) to build much of its machinery, including the Bombe machines. However, in 1940 BTM was struggling to provide the production capacity to fulfil all of the tasks GC&CS demanded

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Mahon, *The History of Hut Eight 1939 – 1945*, HW 25/2, TNA, 29.

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Mahon, *The History of Hut Eight 1939 – 1945*, HW 25/2, TNA, 23. See also Grey, *op. cit.* (ref. 12), 184.

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of it. In November 1940, for instance, BTM wrote to GC&CS stating that unless GC&CS reduced its orders, either of Bombes or alternatively of other equipment, production would be delayed.[45] Meanwhile, BTM was not solely contracted to work on GC&CS's materials, and had government orders, of high priority, which also demanded its manufacturing resources. The result of these combined pressures unavoidably led to problems of prioritisations.[46] The cost of each individual machine, after the initial substantial cost to design and build the prototype machines was also relatively high. In December 1940, when GC&CS contacted BTM regarding placing an order for a further 12 machines, BTM quoted a base figure of £7,500 per machine.[47] Given that the annual salary of a cryptanalyst, of the Civil Service rank of Junior Assistant, was between £260 and £400, the cost of 12 machines was much as the annual cost of 225 cryptanalysts.[48] Furthermore, according to GC&CS estimates made in late July 1942, each machine required approximately 10 staff, comprised of operators and mechanics, all of whom

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Mahon, *The History of Hut Eight 1939 – 1945*, HW 25/2, TNA, 29.

45 Baillie to Travis, 13 November 1940, HW 62/4, TNA.

46 C. Mead to Col. E. S. Briggs, 5 March 1941, HW 62/4, TNA.

47 Baillie to Travis, 2 December 1940, HW 62/4, TNA.

48 [No author given, but certainly written by Alistair Denniston as confirmed in later documents within the file] to C.S.S. [Chief of the Secret Service], 'Pay of Cryptographers.', 13 August 1941, HW 64/47, TNA.

required accommodation, rations and pay, massively inflating the investment required to mechanise the exploitation of Enigma traffic.[49]

Looking at the issue retrospectively A. P. Mahon wrote in 1945 a short summary of the difficulties, noting,

> A further difficulty was that the Bombes - essential to complete the break on modern keys - did not start to arrive until the summer of 1940 and the German Air and Army section working on Enigma (Hut 6) also needed these machines. Thus the testing of even one crib, supposing this to be available, presented a considerable problem. …
>
> Failing a pinch or a really large number of Bombes there was little hope of any progress on up to date material.[50]

The arrival of the machines generated disputes regarding which service, the Army, Air or Navy, should have priority of use, was met with the same *ad hoc* attitude as displayed by GC&CS when faced with the problem of Enigma and the development of the Bombe machines. Little planning for the distribution of machine time was evident, and it was not

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49 [No Author Given] 'Locations and Numbers', 29 July 1942, HW 62/4, TNA.

50 A 'pinch', was the physical capture of key cryptographic information or machines from an enemy power. Alexander, *Cryptographic history of work on the German Naval Enigma* (no date, c. 1945), HW 25/1, TNA, 22.

until 1942 that serious attempt at establishing an administrative infrastructure to allocate Bombe time was established.[51]

Given that the first Bombe machine was delivered to Bletchley Park around two years previously, and that the early Bombe period in Enigma cryptanalysis was problematic due to limited numbers of machines, the failure of the agency to adopt a system in which to efficiently organise Bombe time is remarkable. Despite the severity of these problems, the agency was willing to ignore them, without instituting administrative measures, for an exceptionally lengthy period of time. So why, after two years, did the agency determine to institute a change at that point? The internal histories of GC&CS provide few answers. Alexander notes that "sudden demands" for machine time by Hut 8 would "seriously disrupt" the work of its sister Enigma cryptanalysis section, Hut 6. Firstly, it therefore seems reasonable to speculate that, despite the growing number of Bombe machines, the impact of these disruptions had increased in number and intensity. Secondly, the introduction of this measure was at least partially a product of the wider administrative revolution within the agency – the February 1942 reorganisation of GC&CS.[52]

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There is dispute among the internal histories of GC&CS precisely when this arrangement took shape, Alexander suggests that the system was adopted in the spring summer period of 1942, while Birch states that it was adopted in early 1942. Alexander, *Cryptographic history of work on the German Naval Enigma* (no date, c. 1945), HW 25/1, TNA, 37; Birch, *The Official History of Sigint*, Vol. 1 (part 2) and Vol. 2, 101.

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The reorganisation of GC&CS was prompted by considerable dissatisfaction both within GC&CS and from its client ministries with the organisational apparatus within GC&CS - of which the failure to produce an adequate system for distributing Bombe time was symptomatic. The consistent bottle-necks within key GC&CS processes, such as Bombe allocation, created by an increasing volume of intercepted wireless traffic and the failure of the agency to acquire sufficient materiel and workers, to match these increases made it increasingly difficult for the agency to produce enough material to satisfy its customers.[53] These problems, combined with a series of managerial disputes within GC&CS, led to overhaul of the administration of GC&CS starting from the top. Alistair Denniston, the head of GC&CS since its formation in 1919, was sidelined and placed in command of GC&CS's diplomatic and commercial section working from London. His erstwhile deputy, Edward Travis, took over command of Bletchley Park, and GC&CS's efforts to read Axis military traffic.

Travis' promotion led to a great many changes within GC&CS. Several heads of key sections, such as Alan Turing, who provided key insights into the work of cryptanalysis

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For full details of this reorganisation, and the changing nature of administrative change within GC&CS across the war as a whole, see Christopher Grey's recent analysis of the agency's organisation and management. Grey, *op. cit.* (ref. 12).

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but was a poor manager, were replaced and new administrative systems, such as the "Bombe control" committee, were established. However, as Christopher Grey notes, this solution to the problem of Bombe time was far from guaranteed to be a success and, importantly, that the various parties involved had to come up with their "own solution" – highlighting the *ad hoc* nature of the solution.[54] In the end it was successful, in part, Grey argues, because the committee was comprised by individuals who were in many cases already friends and had been so since before the war. Therefore, inter-service rivalry, which had exacerbated the problem in the first place, was not as prominent within the committee as it might have been and was elsewhere at Bletchley Park.[55]

Meanwhile, GC&CS was able to recruit more staff and Bombe production was accelerated. For instance, from December 1940 to March 1942, GC&CS grew in size from 674 staff members to 1584, an increase of 910 individuals. Yet in the following nine months the agency had grown nearly twice as much again to 3,116, and in the following year grew by over 3,000 staff members reaching a total of 6,864 by December 1943.[56] Similarly, the total number of "runs" made by the agencies collective Bombe machines increased significantly each year as more machines were added to the pool and more efficient methods were established for their operation and administration. In 1941 Bombe

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Birch, *The Official History of Sigint*, vol. 1 (part 1), 107.

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Quoted in Grey, *op. cit.* (ref. 12), 184.

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Grey, *op. cit.* (ref. 12), 184.

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machines made a total of 1,344 runs, in 1942 this increased to 4,655, in 1943 to 9,193, and in 1944 to 15,303.[57]

Of course, given the size of the machines and the staff necessary to operate them, one of the most serious bottlenecks was solving the problem of accommodating and administering the large number of machines and staff. Despite a considerable building programme on the Bletchley Park estate, to house the agency's growing operations, little consideration had been given to the problem of housing the large Bombe machines. In 1940, a purpose built building, named Hut 11, was constructed to house the machines. However, soon the building proved inadequate and two further buildings were constructed, Hut 11A and Hut 11B in 1942, to increase capacity for Bombes, and the provision of space for the training of new Bombe operators and office work.[58] Earlier still, outstations at the nearby Wavendon and Adstock were established to house Bombes.[59] Hut 11A opened in February 1942, but within a month, new plans for massive expansion in Bombe numbers exceeded the space provided by the new building and

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Johnson, et al., *op. cit.* (ref. 2), 3-10.

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Mahon, *The History of Hut Eight 1939 – 1945*, HW 25/2, TNA, 29. In 1940 a total of 273 runs were made.

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Linda Monckton, Andrew Williams, Imogen Grundon, Nathalie Barrett, and Kathryn Morrison, *Bletchley Park, Wilton Avenue, Bletchley, Milton Keynes, MK3 6EB*, Historic Buildings Report; Architectural Investigation Reports and Papers B/010/2004, vol. 1. English Heritage (2004), 292-308.

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Smith, *op. cit.* (ref. 20), 75.

available outstations, and proposals were made for the establishment of another new nearby facility to house as many as 49 new, upgraded, machines and as many as 640 necessary workers.[60]

These sites were selected according to a number of criteria. Initially, nearby sites were selected, within 25-30 miles of Bletchley Park and with good access to telephone and teleprinter communication. This was absolutely necessary to provide instruction from Bletchley Park's cryptanalysts to these satellite stations. Secondly, they required grounds large enough to house the large machines, but also to house hundreds of Bombe operators who lived onsite. By the height of GC&CS's expansion, in the winter of 1944, there were a total of five major outstations, three located near Bletchley Park at Wavendon, Gayhurst and Adstock, and two further afield at Stanmore and Eastcote. These sites, and Bletchley Park, housed the Bombe section which numbered 256 male Royal Air Force mechanics and 1,676 female Bombe operators, mainly members of the Women's Royal Naval Service, by the end of the war.[61]

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60 [No author given]'Proposals for dealing with 4-wheel – Stecker – Enigma', 10 March 1942, HW 62/4, TNA.

61 Budiansky, *op. cit.* (ref. 8), 304.

This expansion programme was, even after the reorganisation of the agency, prompted by wider developments outside of the agency's control – a major upgrade to the German Naval Enigma system, known as M4, introduced in February 1942. The system altered some of the machines components and introduced a fourth wheel, increasing the number of possible settings by a factor of 26.[62] The increased security provided meant that the existing Bombe machines, while not redundant, would take considerably longer to complete a run, as much as 150 days of Bombe time. At that time GC&CS was running twelve Bombe machines, this meant that even if all twelve machines were set to solving just one day's settings, using the new system, it could take at least two weeks to make a successful run. Furthermore, that would also not leave any Bombe time for work on *Heer* (the ground forces of the *Wehrmacht*) and *Luftwaffe* (the air force of the *Wehrmacht*) material.[63] Clearly this was unacceptable and new methods of attacking the problem would have to be developed. The development of solutions to this problem posed by M4 produced one of the most bitter and protracted disputes to erupt among GC&CS and its contractors, and is worth describing in some detail.

As it was, some tentative research was already being conducted by the physicist C.E. Wynn-Williams, on the development of a new, faster, Bombe machine. Unsurprisingly, the development of M4 added considerable impetus to this project. Wynn-William's idea was to improve the existing Bombe machines with two attachments. A mechanical

62 Budiansky, *op. cit.* (ref. 8), 234.

63 Budiansky, *op. cit.* (ref. 8), 234.

commutator assembly, which incorporated a fourth wheel to the Bombe machine, and a vacuum tube in place of the old electromagnetic relays used by the old machine – this plug-in upgrade to the Bombe was dubbed *Cobra*.[64] Meanwhile, Harold "Doc" Keen, the lead engineer working on the construction of Bombe machines at BTM, began designing his own four wheel Bombe machine in February 1942 and completed designs by the following month – dubbed *Mammoth*. This presented GC&CS with a dilemma; the Cobra system, while concluded to be problematic in a number of respects, it presented the swiftest solution to the problem posed by the M4. Mammoth, on the other hand, promised to be a more flexible machine that could be adapted to a wider variety of problems. GC&CS chose to invest efforts primarily into the Cobra system while also continuing to develop Mammoth as a "second bow" that could be applied to more difficult problems. It was initially decided to build 34 Cobras and only six Mammoths. [65]

However, Cobra development was fraught with problems. Gordon Welchman, who designed an important early improvement to the Bombe machines in 1940, complained that Wynn-Williams was,

> badly let down by his engineering advisers and the workshop in which the first prototype Cobra was built. He was led to suppose that the sensing was key to the

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For a detailed description of the Corbra Bombe, see: David Whitehead, 'Cobra and Other Bombes' *Cryptologia*, 20, no. 4 (1996): 289-307.

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W. G. Welchman to A.D. (S) [Nigel De Grey], 4 June 1943, HW 62/5, TNA, 1.

problem, whereas all subsequent (and previous) experience has shown that sensing is comparatively trivial, whereas the real difficulty was mechanical.[66]

In other words, the engineers falsely concluded that the problem with Cobra was in its vacuum tube sensors when the real problem lay with the mechanical commutator assembly. Tommy Flowers, an engineer from the General Post Office (GPO), who would later go onto lead the team which would design and build Bletchley Park's other towering technological achievement, Colossus computer, was brought into build the sensing unit. However, he went about redesigning the unit, causing friction with Wynn-Williams who suggested that Flower's design was problematic in several different areas. Welchman, the head of GC&CS's mechanisation programme, was brought in to mediate, but concluded that he lacked the technical expertise to come to a definitive conclusion without subjecting the prototypes to further experimentation.[67]

Meanwhile, the Mammoth Machines were developing well, and by October the first of the machines had been constructed and began preliminary testing. This period of testing was aimed at discovering, and solving, problems in the design and manufacture before other machines underwent production. This early model was predicted to be able to complete a Bombe run in 22 minutes. At that time it was hoped that the vacuum tube, or valve, based sensor would be applicable to Keens machine, replacing the relays sensor

66 W. G. Welchman to A.D. (S) [Nigel De Grey], 4 June 1943, HW 62/5, TNA, 1.

67 W. G. Welchman to A.D. (S) [Nigel De Grey], 4 June 1943, HW 62/5, TNA, 2.

and reducing the time it would take to complete a run to 13 minutes. [68] However, Keen hoped to be able to produce a new relay sensor which was capable of achieving the same speeds projected for the valve sensor and set about attempting to design and construct that upgrade.[69]

As noted, at that time, GC&CS was considering the possibility of mixing and matching the various components and machines undergoing design and production in the hope of creating an optimum machine, which they codenamed Centaur. The development of the Cobra Bombes continued, but remained problematic.[70] By October, like Mammoth, a prototype had been built but had failed and projections suggested that a working prototype might not be available for a further eight weeks.[71] Therefore, neither Flowers' nor Wynn-William's sensor was able to be adequately tested because of continued problems with the mechanical fourth wheel.

68 [Unknown Author], 'Production of High Speed Machines: (Second Note)', 14 October 1942, HW 62/4, TNA, 1.

69 [Unknown Author], 'Production of High Speed Machines: (Second Note)', 14 October 1942, HW 62/4, TNA, 1.

70 W. G. Welchman to A.D. (S) [Nigel De Grey], 4 June 1943, HW 62/5, TNA, 3.

71 [Unknown Author] 'Production of High Speed Machines', 4 October 1942, HW 62/4, TNA, 1.

The situation rapidly changed in December 1942 when Bletchley's cryptanalysts, using the old three-wheel Bombe machines, were able to make a break into M4. This altered the situation entirely; no longer did GC&CS need to rush a few machines into production as soon as possible. Instead, they could afford to take longer and fine tune the designs to produce better machines in quantity rather than build a few flawed machines quickly. At that stage, Welchman concluded that it would be better to focus on the BTM Mammoth machine, which was more adaptable.[72]

However, Flowers and Radley still hoped to be able to test their sensor. A proposal was made to allow Flowers and his team to test his sensor on one of the new four-wheel Bombes developed by BTM. However, the obvious objection to that was that it would consume valuable time experimenting with the new machines to find problems that would need to be ironed out of future machines, thus holding up production. Meanwhile, the problems with the Cobra still had yet to be resolved, leaving Flowers in the frustrating position of having a prototype sensor requiring testing, but no four-wheel unit upon which to perform those tests. This, therefore, delayed Flowers work by several months, and eventually Dr. Radley, who was Edward Travis' engineering advisor and working with Flowers' on the sensor, went over Welchman's head directly to Travis and requested a four wheel machine upon which tests could begin.[73] This episode created

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W. G. Welchman, 'Report on Visit to Letchworth, December 3rd.' 4 December 1942, TNA.

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W. S. Radley to Nigel De Grey, 28 May 1943, HW 62/5, TNA; W. G. Welchman to A.D. (S) [Nigel De Grey], 4 June 1943, HW 62/5, TNA, 5-6.

considerable tension among the various design teams, Welchman and Radley, which lasted several weeks and resulted in a number of recriminating letters and reports from both sides of the dispute.

Radley and Flowers were provided the best machine BTM had developed, named Freemantle, and began testing in early May 1943.[74] However, according to Welchman, they failed to abide by the instructions to keep a particular gear wheel well oiled, and they failed to do so. The result was a mechanical failure which badly damaged the machine, which required a month to repair.[75] Radley, on the other hand contended "I cannot in any way agree with Welchman that it [the malfunction of the machine] was due to neglect or interference on the part of Flowers' people."[76] Welchman also accused Flowers and Radley of having an agenda to prove the superiority of valve technology - rather than employing brief experiments to examine whether their own unit would work, which was their mandate, they wanted to perform unnecessary and lengthy tests to prove the superiority of the vacuum-tube over BTMs relays.[77] Radley, on the other hand, argued

74 W. S. Radley to Nigel De Grey, 28 May 1943, HW 62/5, TNA; W. G. Welchman to A.D. (S) [Nigel De Grey], 4 June 1943, HW 62/5, TNA, 5-6.

75 W. G. Welchman to A.D. (S) [Nigel De Grey], 4 June 1943, HW 62/5, TNA, 5-6.

76 Radley to Nigel De Grey, 28 May 1943, HW 62/5, TNA.

77 W. G. Welchman to A.D. (S) [Nigel De Grey], 4 June 1943, HW 62/5, TNA, p. 6.

that those tests were absolutely necessary as was determining which method produced a more reliable machine.[78]

Welchman also described a particularly heated meeting, in which Flowers argued that the relays required too much mechanical precision to work efficiently and that Welchman and Keen were "determined to use relays 'at all costs'."[79] This was, of course, the reverse of the charge Welchman laid at Flowers' door regarding his agenda to force vacuum tubes on GC&CS. According to Welchman, Flowers also attacked Keen's competence as an engineer,

> The B.T.M. machine was thoroughly badly designed, Mr. Keen had created his own difficulties, and Mr. Flowers could not understand how anyone could have done the things that Mr. Keen had done. It was a scandal that after 15 months B.T.M. had not got a machine running.
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> By this time of course Mr Flowers had had Freemantle for over a week and he said that the machine was hopeless and the timing all wrong.[80]

78 Radley to Nigel De Grey, 28 May 1943, HW 62/5, TNA.

79 W. G. Welchman to A.D. (S) [Nigel De Grey], 4 June 1943, HW 62/5, TNA, 6.

80 W. G. Welchman to A.D. (S) [Nigel De Grey], 4 June 1943, HW 62/5, TNA, 6.

Flowers was supported in his attack on Keen by Radley, who proceeded to threaten to go over Welchman's head once again, to Commander Travis, and demand that the entire B.T.M. project be placed in Flowers' hands and given the opportunity to make the machine work. Welchman and Keen concluded that Flowers' technical criticisms were "absurd" and that at least one assertion was "particularly stupid", and strenuously defended the expertise of Keen and his team. Finally, Welchman concluded that Radley held too much influence over Commander Travis and that his, and Flowers', influence "must be completely removed".[81] Welchman also recommended a full investigation of the dispute.[82]

Eventually, the situation was resolved without an investigation, but only when Nigel De Grey, GC&CS's second-in-command, stepped in, heard both sides of the story and cleared the air. Radley repudiated the charges he and Flowers' had levelled at the competence of Keen and his company, and was granted the opportunity to continue experiments of Flowers' sensor on the new four wheel Bombes. However, this only came with provision that neither Flowers nor any of his engineers physically touch any of BTM's machines, and that all the work and maintenance be performed by BTM. This situation appears to have continued throughout the testing phase of the valve sensing apparatus. Eventually, a total of twelve Cobra Bombes were built, and despite the efforts of Flowers to convince Welchman of the merits of the vacuum tube sensors, as opposed

81 W. G. Welchman to A.D. (S) [Nigel De Grey], 4 June 1943, HW 62/5, TNA, 7-10.

82 W. G. Welchman to A.D. (S) [Nigel De Grey], 4 June 1943, HW 62/5, TNA, 10.

to relays, Welchman concluded that "The arguments in favour of valves turned out to be very weak indeed."[83] Following the refurbishment and upgrading of a number of the original machines, and following the production of new machines, the total number of Bombe machines available for operation by the end of 1943 comprised of 87 three-wheel Bombes and 95 four-wheel machines – however, it is important to note that of those 95 four-wheel Bombes available, 75 were constructed by United States Naval cryptanalysis department – OP. 20 G.[84]

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The cryptanalytic alliance between Britain and the United States of America had a profound impact on cryptanalysis during the Second World War. Firstly, thanks to the Lend Lease programme, GC&CS was the direct beneficiary of approximately a million dollars worth of American equipment.[85] Secondly, GC&CS had consistently battled

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W. G. Welchman to D.D. (S) [Edward Travis], 9 August 1943, HW 62/5, TNA.

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Alexander, *Cryptographic history of work on the German Naval Enigma* (no date, c. 1945), HW 25/1, TNA, 57. OP. 20 G, stands for 'Office of Chief Of Naval Operations (OPNAV), 20th Division of the Office of Naval Communications, G Section / Communications Security'. Lord Asa Briggs, the historian and Bletchley Park veteran, recalls a different number in his memoir. According to Lord Briggs the numbers were 16 machines by the end of 1941, 49 by the end of 1942 and 99 by the end of 1943. Asa Briggs, *Secret Days: Code-breaking in Bletchley Park* (London, 2011), 79.

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issues of funding, manpower and other materials throughout the war - particularly during the opening years. Cryptanalysts in the United States, on the other hand, enjoyed considerable access to resources. However, what they made up for in material wealth they lacked in experience and in access to wireless intercept stations. Nevertheless, despite the deficiencies on both sides of the Atlantic, the process of forming a cryptanalysis deal was both long and difficult in the making.[86] Nevertheless, by the summer of 1942 Bletchley had decided to dispatch one of their most senior and gifted cryptanalysts, John Tiltman, to the United States to brief American cryptanalysts on British progress and methods.[87]

Fully appraised of the problems Bletchley Park was having with the German naval Enigma system, combined with the heavy losses British and American shipping suffered at the hands of the U-Boats, US officials were determined to increase Bombe production. After some negotiation regarding the number of machines the US would build, US engineers began the process of designing their own prototype high-speed machine to tackle the four rotor problem. The US navy machine was a little different from its primary British counterpart, including a valve based sensor and a different number of drums. The machine could complete a four-wheel run in 20 minutes and a three-wheel run in a matter

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D.D.(S) [Edward Travis] to D.N.I. [Director of Naval Intelligence, Rear Admiral Edmund Rushbrooke], 11 January 1944, HW 62/6, TNA.

86 For full details of UK USA signals intelligence co-operation see, Bradley F. Smith, *The Ultra-Magic Deals: And the Most Secret Special Relationship, 1940-1946* (Novato: CA, 1992), 122.

87 Smith, *op. cit*. (ref. 83), 122.

of seconds. Furthermore, the British cryptanalysts were impressed with the machine which was deemed to be an improvement on British models.[88]

Moreover, the US manufacturing industry was capable of a quality and speed of work which was beyond the resources of British manufacturers. Initial plans were drawn up in September 1942 and revised plans produced in January 1943, and by May 1st prototypes had been built. The design and production of the machines was awarded to the American National Cash Register Co. in Dayton, Ohio. The company was able to produce machines extremely quickly at a rate of two a week by the autumn of 1943. Obviously, this was far beyond the capacity of BTM. In the end, US Bombe production was limited to around 125 machines.[89] Initially, based on a not altogether rounded view of the problem posed by Enigma cryptanalysis, the aim had been to build over 300 machines in the initial order. However, discussion with experienced British experts, such as Alan Turing, soon led to a downward revision of the order to 96 Bombes.[90]

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88 Mahon, *The History of Hut Eight 1939 – 1945*, HW 25/2, TNA, 89.

89 Mahon, *The History of Hut Eight 1939 – 1945*, HW 25/2, 89.

90 J. N. Wegner, H. T. Engstrom, R. I. Meader, 'Memorandum for the Director of Naval Communications: History of the Bombe Project', 30 May 1944, Record Group 457, Records of the National Security Agency, Box 1414, National Archives and Records Administration Archives II, College Park Maryland. Reproduced online by The Mariners Museum, http://www.marinersmuseum.org/sites/micro/battle_of_the_atlantic/bombe_history.pdf [accessed: 17 June 2013].

The policy of the British and American cryptanalysts was that the US contribution towards German Naval traffic was that the US should be a junior partner. This would allow the US to place the weight of its assets behind the problem posed by Japanese traffic, while allowing British experience and expertise, which was two years ahead, took the lead. As Hugh Alexander described it,

> In the cryptographic field they [OP. 20 G] adopted from the beginning the clearly correct policy of supplementing our work rather than of attempting to cover the whole field themselves. With this end in view they set up a thoroughly efficient and businesslike organization but did not put in it their best cryptographers. They were taking the lead in Japanese cryptography in which there was an immense field to cover and it would have been wasteful to have put their outstanding technical experts on to the Enigma in which the main problems had been solved and in which we had several years start. Moreover they only intercepted a comparatively small amount of German traffic which was another severe handicap.[91]

91 Alexander, *Cryptographic history of work on the German Naval Enigma* (no date, c. 1945), HW 25/1, TNA, 57.

Given the considerable Bombe capacity available in the United States, the policy was clearly a sensible one. When British Bombe time was exhausted, details of the various jobs outstanding, typically, but by no means restricted, to Naval work, would be communicated to OP. 20 G, run on their machines and returned to Bletchley Park within an hour.[92] This ensured that US Bombe machines were being utilised, while also supplementing the limited availability of machines in Britain. It appears inconceivable that the British cryptanalysts, with their limited number of machines and relatively slow production programme, could have been as successful as they were without American help.

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In 1944, Gordon Welchman, looking back on GC&CS's wartime performance, with the aim of informing future performance, summarised the successes and failures of the agency's haphazard wartime programme of mechanisation with particular clarity. He rightly pointed to the mechanisation of GC&CS's processes as of vital importance in the chief successes of the agency. However, he did include a highly perceptive caveat,

> We can claim to have made a pretty good show, but we must admit that in the early stages our handling of production was rather amateur and we did not realise the size of the maintenance problem. But we now know only too well that our

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92 Alexander, *Cryptographic history of work on the German Naval Enigma* (no date, c. 1945), HW 25/1, TNA, 90.

> specialised machinery has only just been adequate for the problems. Small improvements in the enemy's machine sand methods could and may yet defeat us.[93]

The truth of all of these assertions is borne out by an examination of GC&CS's successes and failures in the first half of the war. GC&CS was slow to get to grips with the Enigma problem, slower still to investigate mechanical solutions to the problem and, as Welchman observed, found it very difficult to mass produce those mechanical solutions. Considerable pressures were placed on the contractors GC&CS commissioned to build the machines, often because GC&CS was unsure regarding the direction it wished to pursue. A key example of both elements of Welchman's critique, the fragility of GC&CS's methods to alterations in Axis cipher machines and the mishandling of production, can be observed in the introduction of an Enigma system with a fourth-wheel. For a period of eighteen months, GC&CS vacillated regarding the construction of a mechanised solution which ultimately resulted in rival teams of engineers producing different sets of apparatus, wasting each other's time and resources, and engaging in bitter conflict. Meanwhile, senior individuals within GC&CS, be it Welchman who backed BTM or Ridley who backed Tommy Flowers and his GPO team, took sides. It was only the escalation of the issue to GC&CS's chief administrator and second-in-command, Nigel De Grey that an adequate resolution was found.

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93 A.D. (Mech) [Welchman] to Director [Edward Travis], 10 July 1944, HW 62/6, TNA.

Of course, the sour period resulting from GC&CS's attempts to deal with the problem posed by the addition of a fourth wheel to the Naval Enigma, was only one in a catalogue of problems revolving around the development and production of the Bombe machine. It must be recalled that, as we have seen, the agency met the prospect of designing and building a machine to address a cryptanalytic problem with considerable apprehension. It was only the intervention of individual like Frank Birch, an historian without a technocratic or scientific background, and Alan Turing, a theoretical mathematician and logician, that led to investigation into the Naval Enigma problem and championed investment in mechanical solutions. However, still more importantly Birch championed the problem because he understood the gravity of the problem in the face of war with Germany. Yet even once Bombe production was at last underway little thought and planning had been made to actually accommodate the machines and the vast number of personnel necessary to operate them. This resulted in the wholesale expansion of GC&CS beyond the gates of Bletchley Park. Furthermore, despite constant issues regarding time sharing between various sections of the agency, for use of the machines, no formal plan or agreement had been made to solve this problem until two years after the delivery of the first machine. The failure of the agency, and those in command of its mechanisation programme, to adequately plan how their new machines would be used is indicative of the wider attitude of the agency. The Bombe machines were built to solve a crisis, and resolution of the problems surrounding their use were only resolved in the face of new crises.

Study of Bombe development also reveals much about the role of scientific expertise in GC&CS. It is interesting that the two key figures in obtaining the Bombe project the “green light” were Frank Birch and Edward Travis. These two individuals, both products of GC&CS’s collegiate era were not scientists, expert mechanisers or technocrats, but nevertheless they played an important role in identifying and arguing the case for mechanisation. Therefore, the agency’s scientists, like Turing and Welchman, designed the machines but the battle in the board room for the project was championed by two of the agency’s most senior figures, including its second-in-command. It is clear therefore, that mechanisation was pushed for by both scientists but also senior management within the agency. However, importantly, this key support was available only in times of crisis. This suggests that while pressure from scientists and support from the highest levels were essential, important factors emphasised by Agar and Edgerton respectively, perhaps the most important factor in mechanisation was a constant stream of crises to force the agency into action.

To conclude, the mechanisation of Bletchley Park, and the difficulties discovered in the design and production of the Bombe machine, represents an excellent example of the wider development of GC&CS during wartime. The agency set about mechanising and professionalising a number of its processes as a means of solving problems and widening bottlenecks which restricted its capacity to successfully fulfil its mandate. It did not mechanise these process as part of a wider attempt to improve efficiency, instead mechanisation was characterised by incremental changes to GC&CS’s infrastructure and operations as new problems were identified and solutions developed. Clearly, successful long term planning was remarkably difficult and instead there were a series of *ad hoc* solutions to newly emergent problems. In the internal history of GC&CS written after the war, Frank Birch described the agency as a whole in a manner which is entirely reflected in its attempt to build the Bombe machines: GC&CS was like “a rudderless vessel buffeted about at the mercy of every wave of circumstance.”[94]

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94 Birch, *The Official History of Sigint*, vol. 1 (part 1), p. 90.