"A WAR OF MACHINERY": the British Machine Tool Industry and Arming the Western Front, 1914-1916

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According to David Lloyd George, Britain's first Minister of Munitions, World War I, "the Great War" was a "war of machinery," and required unprecedented supplies of ammunition and the machine tools necessary to make them. In the early phase of the conflict, when the importance of machine tools was not fully recognized, a shortage of ammunition on the western front precipitated a military and political crisis, and led to the formation of the Ministry of Munitions. A trade-off between quantity and quality of ammunition shell (the machined outer metal casing) was a product of the Ministry's directive to increase output as both makers and users of machine tools came under intense pressure to reach their goals. British engineering achieved huge increases in ammunition output in preparation for the Somme offensive, but the complexities of the supply chain meant that makers and users of machine tools put them to use to make ammunition of a type and quality that was to prove defective.

The trench system of the Western Front demanded powerful artillery batteries deploying large volumes of ammunition. The Great War was an artillery war;[1] and "demand from the voracious Western Front soon exceeded the supply,"[2] resulting in a shortage of ammunition. By the spring of 1915, this had precipitated a military and political crisis, which led to the fall of Britain's last Liberal Government.[3] As David Lloyd George, Britain's new Minister of Munitions insisted, the capability of the military to sustain total war demanded the systematic utilization of the nation's industrial capabilities

to fight "a war of machinery."[4] To produce ammunition of sufficient quantity and quality required an unprecedented increase in the deployment of "key" machine tools in engineering,[5] and raised the issue of the time scale under which machine makers were required to operate and the effectiveness of their response to the pressure of demand. This paper first assesses the response of the industry to the escalating demands of war prior to the formation of the Ministry of Munitions in May 1915. Second, it explores the importance of the industry to the ammunition supply chain, linking makers and users, as the Ministry geared British engineering for the Somme offensive of July 1916.

Ammunition production required a range of machines from heavy hydraulic presses to turret lathes, and consequently their effective deployment was vital to facilitate the huge increase in ammunitions produced by a much wider range of general engineering firms.[6] In the first nine months of the war, two basic constraints faced the industry: limited supplies of skilled workers, coupled with industrial relations problems, and reluctance by firms to expand capacity due to their belief in a short war. Compounding these problems, managers had to adapt to the growing organizational complexity involved in expanding machine output. While the government recognized the necessity of mobilizing private industry, in practice, it limited mobilization and appeared committed to a policy of "business as usual." Within a short period, however, the failure to coordinate the competing demands of the military with the need to mobilize an "industrial army," led to serious labor shortages.[7] As War Office (WO) orders accelerated, businessmen fearing disruption to trade cancelled contracts and discharged workers.[8] Machine makers quickly regretted their haste, "bewailing" the men they had "discharged," and those they had lost to the army.[9] As demand increased, labor shortages appeared, and special lathes for turning ammunitions, as well as automatic machine tools, "could not be produced fast enough to meet the requirements of the munitions manufacturers."[10] Labor supply rested with the WO and while Lord Kitchener, Secretary of State for War, was aware that uncoordinated recruitment was counterproductive, recruiting officers continued to take skilled mechanics.[11]

In the absence of government information, the *American Machinist* was the first to conduct a comprehensive survey of labor supply in March 1915. In an industry vital to the war effort, it revealed "remarkable results." Of 114 firms completing returns, 74.6 percent lost between 10 and 29 percent of their labor force (17 percent average) during the first six months, which seriously constrained production.[12] The outcome was lengthened delivery times and acute shortages of lathes for turning casings,[13] and this, coupled with the heavy demand for machines, raised the potential for inter-firm conflict. In the absence of appropriate controls, small machine firms, had to recruit and retain workers in competition with higher wages offered by larger concerns, which resulted in numerous reports of labor "poaching."[14] Furthermore, machine makers faced labor competition from firms that were engaged in other government work. For example, Greenwood & Batley, Leeds, producers of general engineering products, gun cartridges, and machine tools, employed large numbers of "trainee girls" in November 1914 to increase machine output, but many transferred to making army uniforms, which led to "acute" shortages of trained workers by early 1915.[15] Machine makers also faced competition from dedicated armaments producers who, according to the Engineering Employers Federation (EEF),

attracted skilled labor by offering higher wages.[16] In this context, working overtime became "imperative" simply as a means of enhancing earnings to induce workers "to remain with the firm."[17] High labor turnover, according to the Ministry of Munitions, was one of the big problems facing industry as well as good pay and conditions and was a winner in holding labor.[18] Nevertheless, in an unregulated market, makers faced rising wages and labor management issues as the shortage of labor enhanced the bargaining strength of trade unions.[19] In the Midlands, employers were more adept at minimizing conflict. For example, the EEF conceded to the unions in Coventry in March 1915 a guaranteed increase in time rates.[20] In the Johnstone area of Glasgow, however, a strike in February seriously disrupted machine output, with workers refusing to work overtime until wages were increased.[21] Tensions gradually eased by the middle of March, but with a ninety-hour week common, it is not surprising that industrial relations deteriorated. After eight months of war, labor shortages remained acute, the use of overtime was common, and companies like the prominent Glasgow firm of John Lang had their 800 workers operating around the clock on government contracts.[22]

Added to the labor constraint, machine makers themselves acted to limit potential capacity. A common view prevailed that it would be a short war, lasting no longer than nine months to a year.[23] However, as Hew Strachan observes, this was an "illusion." Kitchener predicted three years, and in this, he was not a lone voice.[24] In early 1915, for example, Birmingham machine makers lagged in the completion of new orders, which resulted in an active market for second hand machines as users scrambled to get supplies. They believed that the war would terminate early, and, consequently, that investment in new plants was speculative.[25] Furthermore, anticipating a short war, makers continued to produce for export rather than war needs, as the Machine Tool and Engineering Trade Association (MTETA) persuaded makers to take the opportunity of "capturing German trade."[26] As a result, firms held back investment necessary to increase capacity for war needs.[27] Adding to uncertainty were the inadequacies of the WO contracting system; the EEF complained in January 1915 of a failure to provide "definite and detailed particulars of [machine] contracts."[28] Machine makers were reluctant to rearrange existing plant[29] for war-designed machines that would have limited application, and a belief in an early victory reduced incentives to invest long term.[30] Thus, Oliver Armstrong, chairman of Greenwood & Batley, announced in September 1914 that despite a heavy demand for machines "under prevailing conditions, capital commitments should ... be restricted to the necessity of fulfillment of immediately remunerative contracts." In November, he refused to sanction increased investment for ammunition lathe production, predicting "a glut in the market after the war."[231] In October, the management of the largest machine maker, Alfred Herbert in Coventry, was concerned about the "lock up" of too much capital in government contracts, and as a result, the board deferred an expansion of tool room capacity until January 1915.[32]

Business uncertainty delayed capacity expansion, necessitating the augmentation of output by other means. First, firms in other sectors of engineering diversified into machine tool production. Birmingham Small Arms (BSA), for example, converted its Sparkbrook factory to manufacture special machinery both for its own use and to supply outside firms,[33] and in Lancashire, textile machinery firms converted to the production of

lathes designed for machining ammunition shell. Second, leading specialized machine makers switched their production lines, specializing in powerful machines for cutting ammunition shell,[34] and lighter machines required for manufacturing fuses and other components. In addition, makers that had been supplying colonial markets slowly switched production to meet machine demand from "government contractors."[35] The pace of conversion was protracted, and attempts to improve productive efficiency could prove frustrating. For example, while the production of lathes for turning ammunition shells had "superseded the usual industrial operations," works managers in machine firms confronted the problem of getting increased production from existing shop space because the expansion of the physical layout of plant was in many cases impossible.[36] Moreover, insufficient manufacturing specifications and a lack of proper progress reports in machine firms resulted in machines that were too "complicated ... for the work for which they were required," leading to high costs and low output per machine.[37]

As war demands intensified, firms faced problems in adapting to the growing organizational complexity involved in expanding machine output, and developing a coherent business strategy. A "coherent strategy" is determined by the organizational and managerial capabilities of the firm, and an effective strategy enables mangers "to see organizational anomalies...and sets the ground for bargaining about the resource needs for the core capabilities...a firm must have to take it the next step forward."[38] At Greenwood & Batley, problems related to the ineffective organization of its diverse product lines, which negatively affected its machine tool output. Despite diversifying activities, including the production of large quantities of cartridges for the French, the management adopted a more centralized structure, attempting to increase control over the company's various departments. In September 1914, the board appointed Thomas Greenwood and A. G. Hopper as departmental managing directors, each controlling eight departments, with sixteen departmental managers below them, all vying for resources. In such a structure, managerial friction was inevitable. Greenwood was, by November, pleading for more resources for the manufacture of ammunition lathes, a request contested by Hopper, whose remit was to deliver urgent demands for cartridges. Supporting Hopper, the board delayed the rearrangement of the plant for full capacity machine production until early 1915, bridging the gap in supply by sub-contracting for machines and components to fifty small engineering concerns, which led to further administrative problems. With a commitment to expand machine output in 1915, chaotic organization resulted in each department evolving its own organizational routines, which led in March to inter-departmental conflicts "nullifying the anticipated cooperation which had been relied upon to bring output...up to the manufacturing potential."[39] Organizational constraints also manifested themselves in specialized makers such as Alfred Herbert. The firm organized itself into three departments: machine tools, ancillary small tools, and factoring, the latter engaged in selling and equipping the machines of other firms, both domestic and foreign. Shortly before the war, the Governing Director, Alfred Herbert, had identified a limited coordination and communication between departments, and the need to place the interests of the company as a whole before the interests of any particular department. Consequently, management entered the war facing considerable organizational problems. In October, the works manager reported the

difficulty in supplying machines and his plans for reorganizing the shop floor to balance production between different types of machines. However, he observed that limited tool room capacity restricted output, the tool department supplying scarce machine fixtures to outside suppliers, who in turn supplied machine tools for the company to sell via its factoring department. By January 1915, the management again confronted the problem of deficiencies in ancillary tools, and the wisdom of selling tools to makers of factored machines, all of which illustrated the lack of communication between departments. To increase its own output and maintain its commitment to outside suppliers, management invested in expanding tool room capacity. At the same time, they sub-contracted their own machine patterns to outside firms, selling the resulting output through their factoring department, an issue that raised the problem of coordinating production and factoring to avoid duplication.[40]

These examples illustrate the organizational deficiencies of leading machine makers, and resonate with the advice of Sir C. Gibbs to Kitchener that the ammunition issue was "not a question of the allocation of contracts but of the organization of production."[41] As late as June 1915 in Birmingham, machine makers found that the volume of demand outstripped supply, and the mobilization of the industry was insufficient to meet the demands of factories producing ammunition.[42] Despite WO reassurances in January 1915 that ammunition manufacturers were operating at full capacity, Sir John French, Commander in Chief of the British Expeditionary Force, informed Kitchener in March, that "The delay is really most deplorable," and in June condemned underestimates of ammunition output for restricting the military's offensive capabilities.[43] In response, Sir Stanley Von Donop, of the Government Ordinance, turned the problem to supply, citing insufficient machining capacity at the Elswick Ordnance Co., Vickers, Beardmore, and Coventry Ordnance. Insufficiently organized supply predicated an "unforeseen" war involving "continuous artillery action."[44] This was the industrial background to the "ammunition crisis" of May 1915, which led to a coalition government.[45] Emerging from this political reconstruction was a key institutional innovation, the Ministry of Munitions, whose remit was to organize the ammunition necessary to support a decisive breakthrough on the western front, and subsequently support the preparation for the Somme offensive. Achieving this was largely dependent upon two interrelated factors. First, the recognition that a "rapid multiplication of machine tools lies at the very root of the solution of the problem of producing more ammunition."[46] Second, an unbending commitment to increased quantity, carrying with it an inevitable trade-off with quality, determining not only the volume but also the type and reliability of ammunition fired on the Somme.[47] According to Strachan, the trade-off was the penalty "for any massive industrial conversion," a result of lowered inspection standards, the deployment of ill-qualified firms, and the dilution of labor, a strategy which concentrated skilled workers on skilled tasks, leaving less skilled operations to semi/unskilled workers, including women. Consequently, the trade-off was the outcome of the military demand for increased output, and the Ministry inevitably confronted "a short-run choice between quantity and quality."[48] Strachan's emphasis on demand-side factors, however, requires qualification. There was no question of a "ammunition crisis" after May; the Ministry presided over a rapid increase in output (Table 1), but this was a function of the interaction between demand and supply.

Table 1. Output of Ammunitions Delivered to Bond (Million)

1915		1916			
3rd Qtr.	4th Qtr.	1st Qtr.	2nd Qtr.	3rd Qtr.	4th Qtr.
2.3	4.4	6.9	8.8	8.9	9.0

Sources: NA, MUN5/136/1000/3, Review of Munitions Output, 1914-1918.

During the "ammunition crisis," Lloyd George had argued that the "failure" of supply was a consequence of the inability to mobilize adequately Britain's industrial resources, which he considered enormously superior to those of the Central Powers. Accordingly, engineering was required to mobilize war work, and he urged ammunition producers to ensure "that you are well represented in the shot and shell that is going to be hurled at the enemy."[49] Thus, augmenting supply became a key factor in British offensive planning; it determined relations with engineering and initiated a trade-off between quantity and quality. On the quantity front, constraints continued, practically all Ministry contractors failed to meet deliveries of ammunition shells and fuses, and acute shortages of 4.5-inch and 18-pound highly explosive (HE) ammunition.[50] Sir Frederick Black, Director General Munitions Supply, observed a failure to supply within contract, from which he had received no full explanation from ammunition contractors. Forecasts indicated that ammunition would arrive too late to meet the demands of an offensive in the spring and summer of 1916, and Black recommended both "hustling" and assisting ammunition producers, the latter prioritizing the delivery of vital machine tools.[51] Even by December, Lancashire contractors were complaining of late delivery of specialized machines, important to ensuring production targets and meeting the technical and quality specifications in the machining of ammunition shells.[52] This was a symptom of a national problem recognized by the Ministry,[53] and by Lloyd George as undermining the whole production drive.[54]

In July 1915, government "control" of machine tools was "tightened" to "hasten the increase of production."[55] Headed by Alfred Herbert, a Machine Tool Department (MTD) of the Ministry assumed control over contracting, prioritizing orders to firms with the equipment and experience to manufacture machines for the production of ammunition shells,[56] and insisting on specialization to avoid retarding output.[57] The Ministry also assumed control over strategically important firms, promoted National Shell Factories (NSF) and National Projectile Factories (NPF), and munitions areas and district munitions boards to coordinate ammunition supply by contracting to several hundred engineering firms.[58] In machine making, the MTETA guaranteed full cooperation on schemes for controlling their factories, and supported recommendations in the Munitions of War Bill, July 1915, for the exemption of machinists from military recruitment, and the return of trained mechanics from the armed forces.[59] Coordination problems persisted; Lloyd George informed Greenwood & Batley that every firm demanded skilled labor, but because of WO recalcitrance, "I cannot get them out."[60] By November, although machine makers had made efforts to increase productivity, labor shortages resulted in an output considerably below mechanical capacity, with night shifts in Birmingham restricted and makers forced to extend overtime to manage the labor problem.[61] Given these constraints, dilution of the male work force became a priority. The substitution of female workers,

however, was a protracted process. A retrospective report of September 1916 to Dr. Christopher Addison, who became Minister of Munitions in December 1916, agreed that the MTD, from its inception had realized the importance of integration, but had confronted "very great difficulty introducing women."[62] By October 1915, the machine tool trade employed only 500 women, out of 35,000 employed, and with night workers representing only 7 percent of day workers.[63] By January 1916, women still represented only a small proportion of total employment, and night work was still restricted (table2).

Table 2. Employment in Machine Tool Trade

	Jan. 1916	Feb. 1916	March 1916	April 1916	May 1916	July 1916	Dec. 1916	March 1917
Men	41173	41606	41913	41013	39711	38313	32624	33770
Women	1096	1471	2079	2341	2676	3122	3118	3611
Night Shift	3471	3669	3791	3933	3615	3579	3579	3437
Total	42269	43077	43992	43351	42287	41435	35742	37381

Sources: NA, MUN 2/24, Ministry, Secret Weekly Report, 6 May 1916; MUN 2/25, Secret Weekly Report, 17 March 1917.

Following discussions with the WO on "grave" shortages of machines, Lloyd George convened a meeting with forty leaders of the industry in January 1916. Crucial to supplying ammunition for a military breakthrough was a major program to enhance machine output. Typifying his belligerent style, Lloyd George attacked the delivery record of the industry. He alleged that a majority of firms had failed to meet deadlines for the NSFs and NPFs, a performance that would lead to military failure. Two specific complaints followed: a low level of night work, with 90 percent of machinery idle at night, and low numbers of women. A visit to John Lang illustrated the case: women were involved in "work of the lightest character ... To call it skilled work is perfectly ridiculous."[64] Langs represented a test case for Ministerial authority, the number of women employed falling from fifty to twenty between September 1915 and January 1916, compared to a workforce of 1,000 men.[65] Lloyd George acknowledged union "prejudice," but he recognized that machine makers did not unanimously endorse the employment of women. Alfred Herbert also castigated the reluctance of employers, and Harold Butler of Halifax, claimed that firms who were willing to employ women were "held back ... by the large firms who have set their forces against it." Machine makers objected to dilution on three grounds: First, they complained that the WO failed to return skilled men from the army, which limited the number of supervisors on night work. Second, they believed that dilution would lead to deteriorating labor relations.[66] Finally, dilution was not compatible with the specialized work in the manufacture of machined components for machine tools. For example, proposed trials with female workers in Glasgow in late 1915 met postponement, as employers challenged the capability of women to undertake accurate machining on specialized work.[67] As Thomas Greenwood observed, the divided industry was between firms producing heavy and light machine tools. The latter was more conducive to dilution involving repetitive work, enabling unskilled women to make more money, and Greenwood recommended transferring men doing light work to firms entailing heavy work, although he recognized the logistical problems.[68] Dilution, as Lang

accepted, required a gradual approach, as women required training in specialized machining operations.[69] Such rationalisms did not confront the crisis of war. Women represented a great reserve of labor, given the competing demands of army and industry, and Lloyd George warned makers, "you are working with your house on fire, and there is no time to consider what you would do in ordinary conditions." Responding to this reality, machine makers unanimously passed a recommendation to increase female employment.[70] During 1916, Ministry pressure on makers intensified, as it redirected skilled labor to aircraft production and the NSFs,[71] which resulted in female employment trebling between January and July (Table 2). Only by forcing the unions and machine makers to accept women, had the Ministry saved the situation.[72] By November 1918, women contributed nearly one-quarter of the industry's labor force.[73]

With the push for increased output, the question of quality became a major issue in the chain of ammunition supply. The trade-off was prominent in the deliberations of the Armaments Output Committee in April 1915, chaired by George Macaulay Booth, a businessperson. Taking "the military view," Booth insisted that a drive for quantity should not result in less rigidity of inspection or of lowering the standard. Presently, "the standard...is high...it is better for our troops to feel confident than for them to have more." Booth recommended standards set by the specifications of the military and its ordinance factories, but ammunition producers, exemplified by Holberry Mensforth, the General Manager of the British Westinghouse, wanted greater tolerances in the specifications. Mensforth did not discount quality, but asserted that the application of rigid specifications to the machining of ammunition shell meant that manufacturers were reluctant to invest in increasing machining capacity: "One feels uncertain as to the limits. If a man...went over the drawings again and said: these are the essential parts, and we must have them accurate but the others we can allow more discretion upon, I am sure you would get a greater number of machines put on the work." In the formulation of policy, Booth agreed to take into account the issue of design specifications, but not at the expense of lowering quality and increasing risk.[74] The pattern of events, nevertheless, was shifting from Booth to the armaments producers as the Ministry, driven by Lloyd George, gave priority from June 1915 to increased output. For example, at Greenwood & Batley, Ministry pressure to increase the output of French cartridges intensified, regardless of the warning by Armstrong that they were constrained by shortages of high precision machines, and that to concentrate on quantity would "incur undue risks." Accurate machining required specialized machines, which had to be adapted by experimentation in design, material usage, and operation, to meet the commercial test of quality, and avoid "duds" that had occurred in prototypes. Oblivious to quality, Lloyd George considered it "absurd....You undertook to deliver at the end of April [1915] and you have delivered nothing," and he threatened direct ministerial control.[75] The drive for output led to an inevitable concession on quality, and Black informed Lloyd George that to accelerate ammunition supply necessitated the simplification of specifications and "Removal of all delays in inspection."[76] Consequently, during the second half of 1915, there was rising concern over quality. Von Donop reported the premature bursting of ammunitions, which he attributed "to defective manufacture, assembly and inspection" of the ammunition casing, "due to the enormous increase of output that has been required." Increasing output

resulted in a "divorce between design and manufacture," as ammunition manufacturers pushed for relaxing rigid specifications, and pressed "for the acceptance of an admittedly inferior store accompanied at times by a reduction in the factor of safety." The authorities faced a fundamental dilemma: to guarantee the quality of ammunition dispatched, or not hamper supply by imposing rigid specifications. Specifications were relaxed, and changes in design approved to facilitate increased output. As Von Donop concluded, there had never been a complete understanding between manufacturers, the Ministry, and the "Director of Artillery" on the trade-off between quantity and quality, and by May 1916 "the divorce between design, supply and manufacture had become...pronounced," which resulted in an acknowledgement of inadequate procedures.[77]

Raising output necessitated an increase in both the utilization of the existing stock of machine tools and an expansion of new specialized machines for ammunition shell work. As Alfred Herbert recognized in July 1916, special lathes for machining the metal casing of ammunition were in short supply, forcing producers to accelerate output "with what is at present available."[78] Consequently, as utilization increased, there was a deployment of inappropriate machines, compounded by the spread of general engineering firms producing ammunition, which intensified the problem of reconciling quantity with quality. On the one hand, professional engineers, such as James Keith, could prioritize quantity, observing that when engineering firms were at full capacity, machine tools constituted a bottleneck at the start of the supply chain. Thus, he advocated high volume utilization of existing machinery, and rationalized that it was not feasible to wait until new specialized ammunition turning lathes became available.[79] On the other hand, the production engineer, H. P. Wally, acknowledged that there were "hundreds of firms" unsuitably equipped to manufacture ammunition shell.[80] Faced with unprecedented demand, they were forced to adapt existing machinery because of the expense of ordering new tools and delays in obtaining them.[81] Expanding supply across a wider number of general engineering firms raised concern over the quality of existing machinery, especially given the small scale and the extensive use of sub-contracting. The Birmingham Munitions Board informed Lloyd George in May 1915 that it was impossible to get a clear estimate of ammunition-making capacity because "the engineering sector was honey-combed with sub-contracting between firms."[82] This, as Wally acknowledged, inevitably meant a significant variation in the quality of the machines utilized, as sub-contractors applied tools designed for other purposes than ammunition shell making, or employed those requiring urgent repair. Equally important, munitions work required accurate cutting and shaping. Thus, machines not specially designed for such tasks required a good staff of toolmakers, and tool room machinery to fabricate tools and rigs necessary to adapt the machine tools to the special work.[83] Firms with insufficient specialized machinery tended to lack skilled tool room workers, which affected the quality of production. At the Bradford NSF, the bulk of lathes were second hand, causing numerous faults in machining the casing, which seriously affected the accuracy of the finished ammunition, but also restricted output through constant repairs, as was the case at the Leeds NSF.[84] NSFs were controlled and operated by Area Boards; lodged in temporary premises the government-owned machinery consisted of "a very scratch lot." In the organization of machine supply, NSFs took second place to the most important engineering firms, who either sub-

contracted to specialized armament firms or contracted directly to Area Boards, and their influence with machine suppliers was such that few machines were allowed outside those privileged rings. Priority also went to NPFs specializing in heavy ammunition, and leased by the Ministry to prominent armament firms.[85] In June 1916, ammunition production by private concerns in Glasgow had a 10-week delay. The NPF of W. Weir appropriated the best machines and engineers had limited skilled labor to adapt existing equipment.[86]

While NPFs received a higher priority, these too experienced problems in machine supply, as documented in a report for Addison shortly before the Somme. Cammell Laird, managing the Nottingham NPF, reported delays in supplying HE ammunition resulting from non-delivery of machine tools, one of many instances in the report.[87] In January 1916, machine orders for NPFs totalled 9,091, and deadlines for completed delivery were set for May. By that date, deliveries were only 6,888.[88] Nevertheless, the report concluded that generally the NPFs had been adequately equipped, the main concern turning on the problem of defective machinery and breakages of machine tools. Beardmore and Co., of the Cardonald NPF, delivered by early July just 300 cases for HE ammunitions per week out of a contract for 6,000, because of difficulties in "rectifying" machine faults and similar problems existed at its Miles End NPF in Glasgow. The quality of machine tools created bottlenecks in shell output, compounded by the limited capabilities of tool room labor. Thomas Firth & Co., Tinsley NPF near Sheffield, complained of the "scarcity" of toolmakers to rectify breakages of machinery caused by utilizing semi-skilled labor, and its factory delivered only half its contracted output for HE ammunition in early June.[89] By July, only 41 percent of delivered machine tools were operational in the NPFs, 72 percent of staff at work, and ammunition shell production only 20 percent of designed capacity, the discrepancy between machines and workers is explained by the need for training tool room labor.[90] For Addison, the root cause of the output problem lay with "faulty management and want of foresight," and especially the general failure to train tool setters adequately. For example, Firth established at Tinsley a training scheme for tool setters designed to reduce the number of breakages, adopting the program pioneered by Harper, Bean & Co., of the Dudley NPF, under the auspices of the Ministry's training department. The experiment proved unsuccessful; while Harper, Bean & Co. produced 84-trained workers, Firth managed only 13, the discrepancy "entirely due to internal causes." The Ministry itself was partly culpable, failing to coordinate the scheme. Its training department, which assisted Firth, confronted a rival MTD scheme, staffed by consultants from Alfred Herbert, which resulted in "constant friction."[91]

"A War of Machinery" required adaptability in the supply chain, and this was certainly evident in the preparations for the Battle of the Somme, which influenced the type of military hardware and components demanded. Consequently, as Feldman argues, an element of uncertainty entered into contractual relations for the manufacture of ammunitions, "for changes in demand from the front necessitated changes in types ordered."[92] For example, the Ministry contracted W. G. De Cros & Co. to produce 6,000 6-inch ammunitions per week, but two weeks before the Somme, it registered a shortfall of 58 percent, a result of delays in machine supply, itself a consequence of changes in shell design which necessitated changes in cutting tools.[93] In the wake of the Somme, a conference of area boards confronted the design issue. Consistent with its policy, the

Ministry insisted upon increased output with the existing machine stock, but Mensforth objected, and raised the quantity-quality trade-off. Increased output, especially of a newly designed bottle shaped casing, was contingent on an increased provision of special machinery, ensuring not only accuracy, but also the avoidance of difficulties, which inevitably arose in the production system due to numerous components requiring machining. An East Anglian manufacturer observed: "cannot we after 2 years and more...settle on a design and stick to it? It is the only way to get output...even though it may not be the best."[94] A Ministry Memorandum concurred: although design changes were unavoidable, it "was one of the greatest causes" preventing rapid output. In the production of the ammunition casing, for example, serious problems arose with Ministry instructions to convert to incorporating a separate nose or base, enabling more efficient block filling at filling factories.

Changes in ammunition specifications were minimal compared to those for fuses, the domestic production of which was still only a fraction of its potential, if firms had "been allowed to have a straight run at the work." Further, shortages of gauges, both on the shop floor and in inspection departments delayed manufacturing, and caused deep concern about machining accuracy,[95] as did variations in inspection efficiency at area bonds, which contributed to manufacturing difficulties.[96]

The supply of ammunitions to the Western Front was a complex chain, added to by the varieties of ammunition produced. Depending on the type, not every process in the manufacture of the ammunition shell required special purpose machine tools. An ordinary shop with decent tools was capable of machining to WO standards."[97] However, ordinary equipment, a reference to the traditional British general-purpose machine which could be adapted to a wide variety of uses, was more applicable to manufacturing shrapnel ammunition,[98] rather than HE ammunition, "because it was metallurgically ...more straight forward."[99] The volume production of HE, compared to shrapnel, involved special purpose machines to undertake twenty-nine individual machining operations, utilizing thirty-nine workshop gauges and twenty-one inspection gauges to ensure the higher accuracy required in production.[100] Harper, Bean & Co., for example, contracted to produce both shrapnel and HE, but concentrated on the former due to insufficient specialized machinery and gauges for the manufacture of HE.[101] As Addison acknowledged in December 1916, the MTD should restructure orders for vital war work from the manufacture of general purpose to special purpose.[102] Nevertheless, the logic of output pushed users in the direction of general purpose, which reflected the standard machine manufactured by British makers, and explains the bias towards shrapnel ammunition. In fact, Britain became dependent upon large imports of specialized machines from the US to augment supply, as well as specialized gauges to ensure accuracy.[103] Machining accuracy lay at the center of the quality problem; even users of ordinary equipment required engineering precision, as ammunition casing made from high tensile steel was difficult to machine and needed a high degree of finish and accuracy.[104] The fact that 30 percent of ammunition fired on the Somme were duds testifies to the specific technical difficulties of British engineering and its machinery equipment.[105] The priority given to the production of shrapnel, and the subsequently disproportionate lower output of HE, suggests that British engineers had little technical

knowledge of the machining processes involved in the manufacture of the latter type. Some machine makers appreciated the significance of this knowledge gap. In November 1916, the directors of Alfred Herbert were concerned about a deficiency of information between users and makers in the technical specification of high precision special machines for volume output. The firm's technical capabilities formed a resource of useful information, but users did not readily assimilate this, as there was no competent department to collect and make use of it.[106]

The study draws four main conclusions. First, machine tools were of critical importance to munitions production. By March 1915, machine makers lost 17 percent of their skilled labor, and this data, supplied by the American Machinist, rather than the British authorities, suggests that the latter had not fully understood the role of machine supply to ammunition production. Second, labor shortages and organizational constraints at the level of the firm held back the supply of machines, and this imposed constraints on ammunition shell output, which manifested itself in the "ammunition crisis supply" of May 1915. The outcome was Lloyd George's construct of a "War of Machinery." Third, the Ministry's focus on mobilizing supply demonstrates its recognition of the key role of machine tools, and its relationship with industry demonstrates the complexity of the supply chain for both makers and users. The Ministry's output drive pushed makers and users to adopt dilution of the male work force, but its acceptance by machine makers was uneven and protracted. It was not until 1916, too late to influence the Somme that the use of female workers accelerated in machine shops. Finally, in preparation for the Somme, the Ministry supplied a vast increase in ammunition, but Strachan argues that quantity was at the expense of quality. Accepting this proposition, the trade-off was nevertheless far more complex. The organization of supply received insufficient attention, due to the structure of the machine tool industry, and the range of constraints faced by both makers and users. For example, British makers produced general-purpose machines, skewing users towards the manufacture of shrapnel rather than HE ammunition. A series of other factors affected the quantity-quality trade-off, including a lack of accurate gauges, inadequate training for female labor, numerous machine breakages, and constantly changing specifications. A consequence was that while quantity certainly increased, this was at the cost of a high proportion of defective ammunition. Firms were urged by the Ministry to manufacture the maximum possible quantity, while Army Officials wanted increased "stringency of inspection, because of the number of premature [explosions] and other failures at the front."[107] On the Somme, the British paid a heavy cost in lives per mile of front gained. While this was a result of a series of factors, one cannot ignore that the problem traced back to the beginning of the supply chain. Machine makers responded to the output drive, providing more machines, which users employed in making a type and quality of ammunition that could not provide the Army on the Somme with the offensive capability that it needed.

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