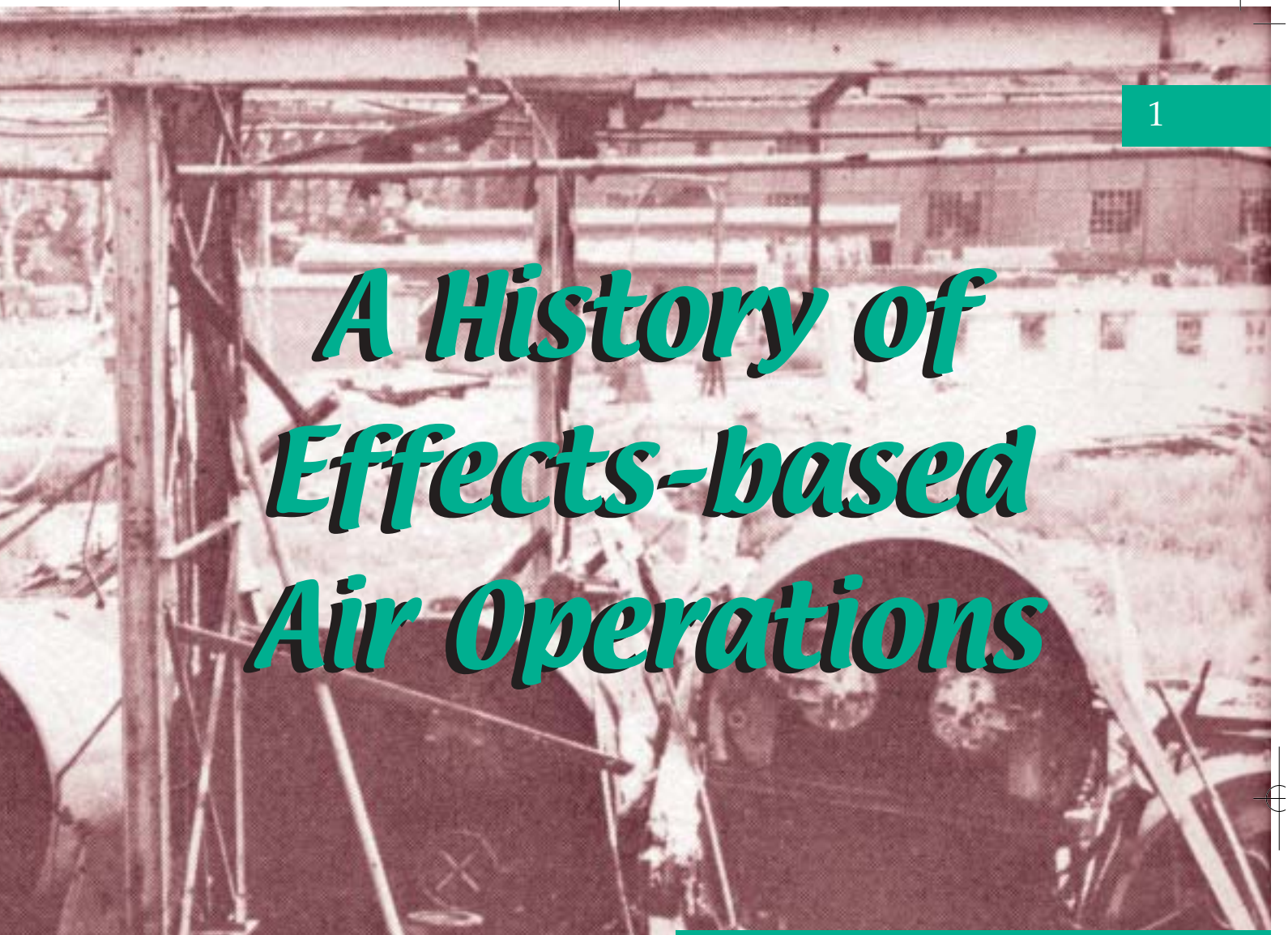
A History of Effects-based Air Operations



By Phillip S Meilinger

Phillip S. Meilinger is a retired US Air Force colonel and command pilot with a PhD in military history. He is the author of 4 books and over 60 articles on military theory and operations. Currently he is the deputy director of the AEROSPACENTER at Science Applications International Corporation.

US Joint Forces Command defines effects-based operations (EBO) as follows: '*A set of actions planned, executed and assessed with a systems perspective that considers the effects needed to achieve policy aims via the integrated application of various instruments of power.*' This is not the clearest definition I have ever read, but it does get across the basic thrust. The success of a military action must be defined by the results it achieves in furthering the political objectives of our leaders. EBO seeks to move away from the linear, attrition-based warfare of the past.

A more coherent though unofficial definition is provided by a RAND analyst:

Effects-based operations are operations conceived and

planned in a systems framework that considers the full range of direct, indirect, and cascading effects, which may—with different degrees of probability—be achieved by the application of military, diplomatic, psychological, and economic instruments.[1]

This is better because it alludes to indirect or cascading effects that may and usually do occur from the application of airpower. It is this characteristic that is so unique to the air weapon, while at the same time being so difficult to measure or even define.

It is my thesis that airmen have always hoped to conduct EBO, even if they didn't use that term, and they sought to do so at the strategic level of war. There's the rub, because up through most of World War II—and some would say even today—airmen did not yet have the analytical, cognitive or intelligence tools necessary to determine the effects or the effectiveness of their strategic air operations. As a consequence, airmen began doing what they *could* do: they began solving the hundreds of tactical and technical problems that constantly cropped up, hoping that by doing things efficiently and competently they would also be doing them effectively. As a tool to achieve this hoped-for effectiveness they took to counting things, mistaking that practice for evaluation and measurement. In addition, airmen often mirror-imaged—they looked at their own complex systems and their vulnerabilities, and then assumed that an enemy's would be similar. Today we have more capable analytical tools to conduct and evaluate EBO, but we still lack a comprehensive and clear methodology for applying them.

Lieutenant Colonel Edgar S. Gorrell, a member of the US Air Service in France, wrote in late 1917 what is considered to be the first concept paper by an American military officer regarding strategic bombing. In many ways this was a remarkable document, and, although largely ignored for the next two decades, it was strikingly similar to what American air theorists would espouse up through World War II. More importantly, it touched upon the basic precepts of EBO.

German artillery was continuously and mercilessly pounding Allied positions, but these millions of shells were produced in only a few specific, well-known factories. If these factories were destroyed, shell production would cease

Allied bomb damage to a German munitions factory at Magdeburg

In Britain, the RAF's 'War Manual,' AP 1300, stated that a nation was defeated when its people or Government no longer retained the will to prosecute their war aim—the desired effect

Gorrell began by noting the ground stalemate on the Western Front that consumed lives to no real purpose. He argued that 'a new policy of attacking the enemy must be adopted.' German artillery was continuously and mercilessly pounding Allied positions, but these millions of shells were produced in only a few specific, well-known factories. If these factories were destroyed, shell production would cease. In other words, if the effect desired was to halt the German artillery attacks, it was not necessary to destroy or overrun all enemy artillery pieces on the Western Front. Rather, destroying the factory that made the guns would have the same effect, but could be achieved, presumably, more quickly and with less loss of life. The same was true of any number of critical war industries ranging from aircraft engines to steel mills.

Gorrell then looked at the German economy as a whole and argued that 'there are a few indispensable targets without which Germany cannot carry on the war.' Regrettably, Gorrell was disappointingly vague on just what those 'indispensable targets' were. Instead, he identified four major industrial *regions* in Germany: a 'Northerly group' comprised of Dusseldorf, Essen, etc; the 'Cologne group'; the 'Mannheim group' that contained Mannheim, Ludwigshafen and Frankfurt; and finally, the 'Saar Valley group' that housed munitions plants and steel works.[2] This was a bit general to say the least. Those geographic regions contained hundreds of potential targets. Which ones were to be attacked and in what order? Gorrell did not say. Unfortunately, those who came after him during the next two decades could do little better.

The American airman, Brigadier General Billy Mitchell, wrote in 1925 that air forces would strike the enemy's 'manufacturing and food centers, railways, bridges, canals, and harbors.'[3] Considering Mitchell's position as Assistant Chief of the Air Service, and also that this quote was from his most notable book, it is apparent that he had made little improvement on Gorrell's very general thinking of eight years previously.

Brigadier General Giulio Douhet, the Italian air theorist, was similarly indistinct in his seminal *The Command of the Air*, first published in 1921 and revised in 1927. Douhet argued that the effect desired in war was the collapse of enemy morale, and this could be achieved through a bombing offensive. Regarding the proposed targets for such an offensive, Douhet identified 'peacetime industrial and commercial establishments; important buildings, private and public; and certain designated areas of civilian population as well.'[4] Realizing that this said very little, Douhet admitted that 'the selection of objectives, the grouping of zones, and determining the order in which they are to be destroyed is the most difficult and delicate task in aerial warfare, constituting what may be defined as aerial strategy.'[5] Indeed, this was where the air commander must prove his genius. What is maddening about these theorists was their absolute assurance that decisive effects would result from bombing key targets, without giving any real guidance as to what those key targets were or how their destruction would lead to the effects desired.

Unfortunately, the official doctrine with which the Royal Air Force (RAF) and US Army Air Forces (AAF) entered World War II offered little more than the standard laundry lists of broad categories. In the US, Army Field Manual 1-5, 'Employment of Aviation of the Army,' stated that 'important objectives may be found in the vital centers in the enemy's line of communication and important establishments in the economic system of the hostile country.' Besides concentrating on enemy forces, the manual suggested such targets as rail communications, bridges, tunnels, rail yards, power plants, oil refineries and 'other similar objectives.'[6]

In Britain, the RAF's 'War Manual,' AP 1300, stated that a nation was defeated when its people or Government no longer retained the will to prosecute their war aim—the desired effect. It would be achieved partly by strategic bombing, which would concentrate on what had then become the usual suspects: the enemy's industrial and economic infrastructure, which included such things as public utilities, food and fuel supplies, transportation networks and communications.[7] I would note that, adding to the confusion such generali-

ties invoked, popular and even professional publications of the time focused on the horrors of air warfare. A common depiction was how air bombardment would destroy whole cities and even civilizations.[8] One is also reminded of the desolation caused by the air attack depicted in the film version of the H.G. Wells novel, 'Things to Come.'

Granted, this is an almost childish example upon which to hang a theory of war, but there was more to it than that. During the 1930s the US, and indeed most of the world, was in the depths of the Great Depression. Businesses and banks, large and small, were closing their doors on an almost daily basis. The economy was a shambles. Great nations were brought nearly to their knees—and not a shot had been fired. It certainly seemed to air planners that economies were fragile instruments and that only a strong economy could build a strong military capability. If the desired effect was to render an enemy incapable of continuing a war, then perhaps airpower, in the form of strategic bombardment, could more directly destroy an economy, and could do so relatively quickly. Victory in war would then inevitably follow. But economies were very big things. One couldn't possibly expect to destroy *every* factory, power station, rail line, bridge, steel plant, etc. in an enemy country.

Great nations were brought nearly to their knees—and not a shot had been fired. It certainly seemed to air planners that economies were fragile instruments and that only a strong economy could build a strong military capability

Theories and apocalyptic predictions of death raining from the sky perhaps had their place to inform or shock the public, politicians and even airmen themselves, but at some point airmen needed to put pencil to paper and devise actual plans. In truth, however, the doctrine manuals published before World War II that contained only vague references to 'vital centers' and 'key targets' were simply inadequate. Nonetheless, throughout the interwar period there were airmen in Britain and the US who began grappling with the problem of how they would actually go about conducting a strategic air campaign.

At the Air Corps Tactical School (ACTS) in Alabama, two events occurred, one admittedly minor that was blown out of proportion, but one that was not so minor. It is an oft-told anecdote that one day the instructors-cum-pilots of the Tactical School learned that they were unable to fly because all their planes were grounded. There had been a failure of a certain spring that went into the propeller assembly on the aircraft engines, but replacement parts were on back order. It seems the springs were manufactured at a factory in Pittsburgh, but due to recent floods, that factory was temporarily closed. No factory; no springs; no flying.[9] This seemed important. If an enemy wished to gain control of the air over the US, perhaps it wasn't necessary to attack every airfield or shoot down every plane. Perhaps it was only necessary to destroy one factory in Pittsburgh.

What targets were more important—or perhaps more vulnerable—than others? The propeller spring seemed to offer a clue, because it implied there were key nodes within an economic system that were more important than others, upon which the system itself tended to depend. All targets were not created equal. The propeller spring became a metaphor for a way of looking at air warfare—the search for the strategic bottleneck.

Before the war, it was extremely difficult for American airmen to obtain information on the economies of potential enemies. There was no funding for such an intelligence organization, and the US policy of isolation made such an endeavor inappropriate. Instead, the instructors at the Tactical School tried a different approach. They looked at ('examined' would be too grand a term)

the industrial northeast of the US. Via letters, phone calls and visits, the officers gathered information on how American power grids, steel mills, oil refineries and transportation systems worked.[10] More importantly, they tried to deduce how those systems did *not* work.

If planners had copious information on the German ball bearing industry, for example, then they might place too much emphasis on that industry's role in the overall war economy

To summarize, going into World War II air leaders had an inherent belief in the importance, indeed the necessity (if partly for institutional reasons to justify an independent status), of EBO. They also had a rudimentary understanding of how such efforts needed to be measured and evaluated. They did not, however, have the analytical tools at hand to conduct that measurement and evaluation.

Once war broke out in Europe in September 1939, both the RAF and AAF expanded their efforts at EBO. For example, the AAF established an air war plans division in Washington and charged it with devising target sets for air attack should the US enter the war.

The initial steps were small and hesitant, but businessmen, engineers and bankers were contacted for information. In some cases this information concerned plants and factories in Europe that American banks had helped finance or that American construction companies had helped build. In other cases, these experts simply instructed the planners on how US systems and networks operated, assuming that those in Germany would be similar. This was very hit-and-miss, often dependent on who knew of someone in business, any business, and how much they were willing to help. There was an obvious danger here, what I call the 'blueprint availability syndrome.' The types of intelligence available and examined will necessarily shape one's view on how a system operates. If planners had copious information on the German ball bearing industry, for example, then they might place too much emphasis on that industry's role in the overall war economy, while at the same time overlooking the importance of another target system. Yet, it was a beginning.

Three other organizations were established in Washington and London that devoted themselves full time to the study of vulnerabilities within the German economic structure. The first was formed by the British government prior to the war and was termed the Ministry of Economic Warfare (MEW). The second group, a collection of American businessmen, lawyers and economists, was called the Committee of Operations Analysts (COA). Finally, a third organization, also created in late 1942, was initiated by two AAF colonels who approached the Office of Strategic Services (OSS, the forerunner of the CIA), and asked for targeting assistance. The Enemy Objectives Unit (EOU) of the Economic Warfare Division in the American Embassy was the result. For the remainder of the war these three new and unusual intelligence and planning units—as well as various other intelligence agencies—would serve as advisers to Allied air leaders.

The objective of all these economic analysis groups was similar. As General 'Hap' Arnold phrased it in his charter to the COA: 'Prepare a report analyzing the rate of progressive deterioration and what should be anticipated in the German war effort as a result of the increased operations we are prepared to employ against its sustaining resources.'[11] Nonetheless, although their goals were similar, these three agencies did not always work in harmony. When Colonel Guido Perera, head of the COA, arrived in England he encountered resistance not only from Eighth Air Force headquarters, but from the EOU and MEW as well. For its part, the EOU encountered resistance from the MEW

and the Air Ministry. As the official history phrased it: 'Capt. Barnett, with ineffable tact, probed the resources of the somewhat reluctant Air Ministry intelligence.' Basically, the Air Ministry felt itself continually 'harassed' by visiting officers bothering them with questions.[12] Relations improved over time, but a degree of competition and friction always remained.[13]

All three of these organizations, as well as the air war plans division on the American air staff, suffered from similar problems. They did not have access to the types of information necessary to make reasoned judgments on the German economy. As the AAF official historians eloquently phrased it:

But there existed in almost every instance a serious shortage of reliable information, and the resulting lacunae had to be bridged by intelligent guesswork and the clever use of analogies. In dealing with this mass of inexactitudes and approximations the social scientist finds himself in a position of no special advantage over the military strategist or any intelligent layman; and an elaborate methodology may even, by virtue of a considerable but unavoidably misdirected momentum, lead the investigator far afield.[14]

To overcome the impediments hinted at here, the analysts initially looked for information in published German magazines and newspapers—hardly likely to be very revealing during wartime—as well as the types of industrial and financial contacts who were located in the US or Britain as noted above.[15] Such poor sources led to one of the greatest misconceptions made by all of these groups for most of the war: that the German economy was drawn taut and therefore susceptible to attack with devastating results. For most of the war the German economy actually contained a surprisingly great deal of slack. Because the economies of the Allies were on a wartime footing, it was simply assumed that Germany's was as well. This was not the case. In fact, the Allies' economies were far more mobilized for war than was Germany's.[16] As an example, the German automobile industry, the largest sector of the economy in the 1930s, was utilized at barely 50 percent of its capacity during the war.[17] On the other hand, some air planners believed that oil offered a special case.

Germany had extremely limited oil reserves within her boundaries; only about 7 percent of her peacetime needs were met by domestic sources. As a consequence, she either had to import this vital commodity, gain access to oilfields and refineries through conquest or alliance, or come up with a substitute. In peacetime, Germany imported virtually all of her oil needs—most of it from Venezuela and the US—but once war broke out, the British blockade removed this option. In 1940, Germany therefore formed an alliance with Rumania to gain access to her vast oilfields, which then supplied her with 60 percent of her crude oil supplies.[18] At the same time, German scientists perfected a method of producing oil from coal in a process called hydrogenation. This process was, and indeed still is, inefficient and expensive.[19] Allied air planners thus saw Germany as highly vulnerable in the area of oil. It was not known, however, how much oil Germany had in reserve when entering the war, nor how much it produced or consumed since then. Indeed, based on little more than guess work, in 1942 the COA estimated that Germany had somewhere between 2.4 and 6.0 million tons of oil in reserve. That's quite a range.

The MEW, for its part, put the figure at 3 million tons.[20] Because there was no agreed upon formula for determining which group's methodology was superior, the issue was decided by simply splitting the difference between the two estimates—the Germans were deemed to have 4 million tons of oil reserves on hand. As a result, when air planners met at Casablanca in January 1943 to determine targets for the Combined Bomber Offensive (CBO), oil was placed fourth on the list—Germany had so much oil in reserve it did little good to make it a high priority. This decision, at least as far the Americans were concerned, would later be seen as an error.

As time went on the COA, EOU and MEW became increasingly more capable in achieving EBO. To a great extent this was due to their formulation of criteria and methodologies for gathering information on the German economy, accessing it, and

Allied attack on a German oil refinery

German aircraft were used up very quickly in combat; there was no real pool to draw from. In this case, destroying the factories would have a significant and almost immediate effect on the Luftwaffe's combat status

then looking closely at the targets themselves. The economists, engineers and mathematicians who comprised the bulk of the three organizations defined their field as they went along. They looked at such issues as the indispensability of the product to the enemy war economy, total production of a given commodity, minimum operational requirements, surplus capacity, ability to substitute other materials, the time needed to repair damaged facilities, the actual degree of damage sustained, and the ratio between 'pool and production.'[21]

This last was important because it identified the distinction between some commodities that could be stored, stockpiled or simply used for an appreciable length of time, versus a commodity where such activities were impractical. Thus, for example, the oil reserves noted above were seen as a large 'pool,' and destruction of production would have little immediate effect; hence, the initial decision of the air planners to give it a low priority. Similarly, U-boat production was slow, most submarines were actually in service or in port, so hitting the factories building the boats would have little immediate effect on operations. On the other hand, German aircraft were used up very quickly in combat; there was no real pool to draw from. In this case, destroying the factories would have a significant and almost immediate effect on the *Luftwaffe's* combat status.[22]

Eventually, the EOU became adept at examining various industries in detail and preparing 'aiming-point reports' that gave specific instructions on how best to destroy those industries. This was a major accomplishment.[23] Once planners had determined which nodes, industries, systems or commodities were more important than others, they had to ascertain whether or not their bombing operations where actually working. There were two fundamental questions to be answered. First, were air strikes actually destroying or neutralizing their intended targets, and second, if they were tactically successful, was that destruction or neutralization having the intended ripple effect throughout the German economy or war machine that had been predicted?

The first question, were the bombers actually hitting and destroying their targets, did not have an obvious answer. The inaccuracy of early bombing efforts as detailed in the Butt Report of 1941 is well known.[24] Two years later the COA formed a subcommittee on 'Probabilities' to determine the accuracy of Eighth Air Force strikes. The task was not easy. Eighth Air Force headquarters was protective of its data regarding bomb accuracy, probably because it revealed that its accuracy was not very good. When the COA finally obtained the data they decided the numbers were 'too pessimistic as a criterion for the future.'[25] This was not a helpful start. In addition, the related question of how much damage was achieved even if the bombs did hit the target was not obvious either. Then, as today, bomb damage assessment was as much an art as a science. Post-strike photographs showed, for example, that the bombing strikes against the ball bearing factories in Schweinfurt in 1943 caused extensive damage. After the war it was discovered, however, that many bombs detonated upon hitting the factory roofs. This collapsed the roofs and such damage appeared impressive in photos, but in reality the machines on the floors below had been largely untouched—less than 5 percent were damaged and most of those were quickly repaired.[26]

Beyond this first level of analysis, the three agencies noted above had to confront the subject of second and third order effects. In truth, all military actions have such indirect effects—some are anticipated and some are not. Identifying these indirect and secondary effects was crucial. To do this it was necessary to identify measures of effectiveness (MOE).[27] Although this is a new term popularized by the Total Quality movement of a decade or so ago, the concept was well understood in World War II. Fundamentally, MOEs link objectives to targets. The analysts realized this and stressed that air targeting boiled down to three basic questions: 1) will damage to the target hurt the enemy? 2) can you hit it and at what cost? and 3) can you damage it if you hit it?[28] Of these, the first was crucial and hinged on what type of evidence, specifically, should analysts look at to determine if their chosen targeting strategies were actually working and achieving the political goals established. The answer to this question was not obvious, and there were several instances during World War II air campaigns when it caused argument.

One example of when this problem became apparent was in the oil plan versus rail plan controversy of spring 1944. The origins of the argument over the most appropriate targets for the heavy bombers traces back to the Casablanca Conference of January 1943. At that conference Roosevelt and Churchill had agreed to a directive that was to be the guiding charter for the heavy bombers. The Casablanca Directive stated that the objective of the Combined Bomber Offensive was 'the progressive destruction and dislocation of the German military, industrial and economic system, and the undermining of the morale of the German people to a point where their capacity for armed resistance is fatally weakened.'[29]

Unfortunately, this was a highly ambiguous directive, perhaps deliberately so, that allowed the reader to take from it whatever he wished. For ACM Arthur Harris at Bomber Command, he saw the order to 'undermine the morale of the German people' as a vindication of his night area-bombing strategy. To Lieutenant General Carl Spaatz, the senior American air commander in Europe, the operative phrase concerned 'the progressive destruction and dislocation of the German mili-

B-24s on bombing mission over Germany

As the AAF official history phrased it, the RAF/AAF bomber offensive was to be a combined effort—the RAF bombing strategic city areas at night, the American force striking particular targets by daylight. In other words, it would not be much of a combined effort at all

tary, industrial and economic system'—the mission of his daylight bombers and their precision bombing campaign. On the other hand, General Dwight Eisenhower, who would eventually be named Supreme Allied Commander for OVERLORD, would focus on the need for an invasion. In his view, the bombers' main function was to support that inevitable assault on the French coast—to ensure that 'armed resistance was fatally weakened.'

In June 1943 the objectives of the CBO were formalized in what was called the POINTBLANK Directive. As the AAF official history phrased it, the RAF/AAF bomber offensive was to be a combined effort, 'each operating against the sources of Germany's war power according to its own peculiar capabilities and concepts—the RAF bombing strategic city areas at night, the American force striking particular targets by daylight.' In other words, it would not be much of a combined effort at all. Yet, POINTBLANK also underscored that the CBO in its most basic sense was to 'prepare the way for the climactic invasion of

In Harris's words: 'Had I paid attention to the panacea-mongers who were always cropping up and hawking their wares, Bomber Command would have flitted continually from one thing to another during the whole period of my command'

Europe.'[30] In short, the problem of Casablanca was still unresolved: differing objectives or effects desired would mean differing strategies, which in turn would mean a different set of targets. Would these varied strategies work in harmony or at cross-purposes?

One other note on POINTBLANK: it stated that an 'intermediate priority second to none in importance' was the gaining of air superiority. As we shall see, how to achieve this effect and how it was to be measured, and, indeed, precisely what the term itself meant, were not obvious to all observers.

By early 1944 planning for the Normandy invasion was in full swing, and the question of how best the CBO could complement the landings was discussed. By this point, American analysts had revised their estimates of the German oil situation and decided the reserves available were not as great as originally thought. If true, then oil should become a crucial and perhaps top priority for Allied bombers. If the oil refineries in Rumania were knocked out, along with the hydrogenation plants in Germany itself that produced synthetic fuel from coal, the vital 'black gold' that propelled the German war machine would be halted—one of the stated goals of POINTBLANK.
Other air planners focused on the German rail network. Troops, supplies, equipment and raw materials all moved around the *Reich* primarily by train—although road and river traffic were also significant. If the rail lines could be cut and the trains stopped, so this argument went, the German war machine, indeed, the entire German economy, would stop as well.

This debate tended to break along national lines with the American airmen pushing for the oil plan and most British airmen—notably ACM Arthur Tedder the Deputy Supreme Allied Commander—advocating the rail, or as they called it, the 'communications' plan. Recall, however, that the Directive was interpreted by Bomber Command to mandate the undermining of German morale. According to this requirement, Harris thought that both oil and rail systems were 'panacea targets' that were distractions from his primary task of area attacks. In Harris's words: 'Had I paid attention to the panacea-mongers who were always cropping up and hawking their wares, Bomber Command would have flitted continually from one thing to another during the whole period of my command.'[31]

The question of oil versus rail was finally resolved on March 25, 1944, when General Eisenhower opted for the rail plan.[32] The critical factor that decided the issue was time. Eisenhower's MOEs were very specific: he wanted Allied air superiority that would then be used to isolate the beachhead area from German reinforcements. He wanted that done *for* the invasion, not sometime in the weeks and months to follow. Although he agreed with the Spaatz faction that the collapse of the oil supply would have a catastrophic effect on the German war machine, such a collapse would not be expected to occur until the fall. That would be too late for his troops in Normandy. The rail plan of Tedder won the day for the quite logical reason that it promised a solution to Eisenhower's immediate problems—it promised the effects that he desired.

To illustrate how much of this was groping in the dark, the US Strategic Bombing Survey later discovered that there actually was a bottleneck—similar to the ACTS propeller spring—that Allied analysts missed. Tetraethyl lead (TEL) was a chemical that when added to gasoline raised its octane level. This additive, discovered in the 1920s, was used routinely by World War II to raise the octane level of gasoline from 87 to 100. This high performance fuel was crucial to aircraft like the Spitfire, P-51 and FW-190. In Germany, there were, literally, only a handful of plants that produced TEL, and all were highly vulnerable to attack. Had the Allied bombers destroyed these plants, German aviation gasoline would have been

rendered nearly useless.[33]
Similarly, another one of the difficulties often experienced in such targeting debates was that of mirror imaging. Time and again Allied air planners and analysts, in the absence of hard data or credible intelligence, made decisions based on their own experience or their own common sense. Sometimes this worked, but on other occasions it induced major errors into their calculations. For example, it was assumed that German hydrogenation plants were built and operated similar to Allied oil refineries. This was not so. The Germans, in an effort to consolidate several processes in the interests of efficiency, tied the production of rubber and chemicals into their hydrogenation plants.

Thus, an air strike on one of these plants affected not only gasoline production, but that of rubber and chemicals as well. In turn, these chemicals (notably methanol and synthetic nitrogen) were often used in other applications so there was a corresponding cascading effect in, for example, the German explosives industry. Allied planners were not aware of this relationship until after the war.[34] This is precisely the type of cascading effect prewar planners had hoped to achieve. Had this information been available in 1944 (along with the importance of TEL noted above), it would no doubt have moved the synthetic fuel plants and oil targets in general higher up the priority list.

Even within the rail plan there was a strenuous debate that is also relevant to our discussion here. If the effect desired was to halt rail traffic, then what specific parts of that rail system should be targeted? There were numerous possibilities: rail cars, locomotives, repair facilities, round houses (switching mechanisms), marshalling yards in general, and rail bridges.

Solly Zuckerman, a British anatomist and primate specialist at Oxford before the war, worked on Tedder's staff in the Mediterranean Theater. Applying himself to the question of what precisely was the best part of the rail system to hit, Zuckerman studied the results of Allied bombing of rail bridges versus marshalling yards in Sicily and Italy during 1943. He concluded that marshalling yards were far more desirable targets simply because they were larger. Given the accuracy of Allied bombers at the time, bridges were so small that it would take a disproportionate tonnage of bombs to knock one out. Because marshalling yards were so expansive, however, Allied bombers were far more likely to hit *something* of value when the yards were targeted. Zuckerman concluded, based on the accuracy argument, that bombing marshalling yards was more *efficient* than was an attempt to bomb bridges.[35] Tedder agreed with this reasoning and directed his planners to concentrate on marshalling yards.

When Tedder and Zuckerman left the theater several months later, the new commander, Lieutenant General Ira Eaker, reviewed the rail decision. His analysts concluded Zuckerman had been mistaken. Using the data from many more air operations than Zuckerman had used in his sample, Eaker's analysts discovered that bridges were not as difficult to hit as previously thought—especially when medium bombers were used rather than heavy bombers like B-17s or B-24s flying at high altitude. In addition, the analysts determined that the results of the bridge bombings were more lasting than were those of the marshalling yards. In the latter case, repairs were often effected within days, but when a rail bridge was dropped, it generally took several weeks to repair it.[36]

This discovery became important as planners grappled with the same issue as they prepared for the invasion of Normandy. If it was desired to isolate the beachhead by preventing German reinforcements from reaching the area—which Eisenhower's decision of 25 March made clear—then how best could airpower achieve that goal? Tedder and Zuckerman, now in London, dusted off their analysis from the year before and once again pushed for marshalling yards. Other analysts in London, led by Charles Kindleberger and Walt Rostow in the EOU, begged to differ. Referring to Zuckerman's analysis as 'tart and turgid,' they sniffed that his 'main conclusions did not, in fact, flow from the mass of appended evidence.'[37] Using the more recent analysis obtained from the Mediterranean, EOU argued for a bridge campaign.

There was enough Allied airpower by mid-1944 to follow a number of different targeting strategies. In this regard, it is always useful to remember that by D-Day, the US Ninth Air Force, which consisted of over 4,000 aircraft, was larger than the entire combat strength of the Luftwaffe

As with the broader question of oil versus rail, this more specific question of 'what rail' broke down by nationality and generated bitter debate—for the next four decades.[38] In the event, air leaders resolved the question of what to strike in their usual manner—they bombed *both* marshalling yards and bridges. There was enough Allied airpower by mid-1944 to follow a number of different targeting strategies. In this regard, it is always useful to remember that by D-Day, the US Ninth Air Force, which consisted of over 4,000 aircraft, was larger than the entire combat strength of the *Luftwaffe*. Moreover, the Allies also had the British 2nd Tactical Air Force and the US Twelfth Air Force in Europe to support the invasion. And of course, from March until September 1944, Eisenhower could also employ the heavy bombers in both Bomber Command and the Eighth Air Force. Given this abundance of air, questions of whether it was better to bomb rail bridges or marshalling yards became almost academic—as for that matter was the question of whether it was wiser to bomb rail or oil. There was more than enough air available to hit all of the above—as well as submarine pens, V-1 and V-2 launching sites, airplane and engine factories, and the enemy front lines.

It would be unwise, however, to pass over this question too quickly. It was and indeed still is of more than academic interest to determine whether Zuckerman was right or if on the other hand the analysts at EOU were correct. Air planners will not always have unlimited air assets at their disposal—even if, as we have seen over the past decade, those assets are limited by political considerations and not due to lack of airframes available. In such circumstances, air planners should know where to get the most bang for their buck. They should know precisely what to hit in order to achieve the greatest effect, and this effect should fulfill policy objectives.

I mentioned that the debate over rail bridges versus rail yards carried on for four decades. That was a good thing, because it allows us today to revisit the methodology and assumptions used by the analysts and planners at the time. In 1970 Solly Zuckerman, by then Lord Zuckerman, published his memoirs in which he once again laid out the arguments for striking marshalling yards. Never a man to mince words, he was somewhat less than charitable to those who had disagreed with him. Not surprisingly, his old antagonists, Kindleberger and Rostow from the EOU, rose to the challenge and there ensued a series of increasingly nasty exchanges in the journal *Encounter*.[39] This exchange of letters to the editor drew out another contestant, Henry D. Lytton, an economist who had worked on the US War Production and Economic Warfare Boards during the war. He sided with his countrymen in a strident article in *Military Affairs*.[40] What are interesting about Lytton's article are not just his conclusions regarding the relative importance of bridges versus marshalling yards—which is perhaps predictable given his background—but his insights into the methodology and assumptions used by the respective protagonists.

Basically, Lytton revealed, using the words the proponents had written in 1944, what were then being used as measures of effectiveness. Zuckerman was interested in the density of the bomb patterns within the designated target area. Marshalling yards were large; thus, a far higher percentage of bombs landed within that area than was the case when the target was a small rail bridge. Kindleberger and Rostow, on the other hand, were less concerned with bomb density than they were with rail movement. If only one bomb in 1,000 hit the bridge—and dropped it—that was preferable to having all 1,000 bombs landing within the confines of a marshalling yard, if even one rail line was left intact in that yard, which allowed

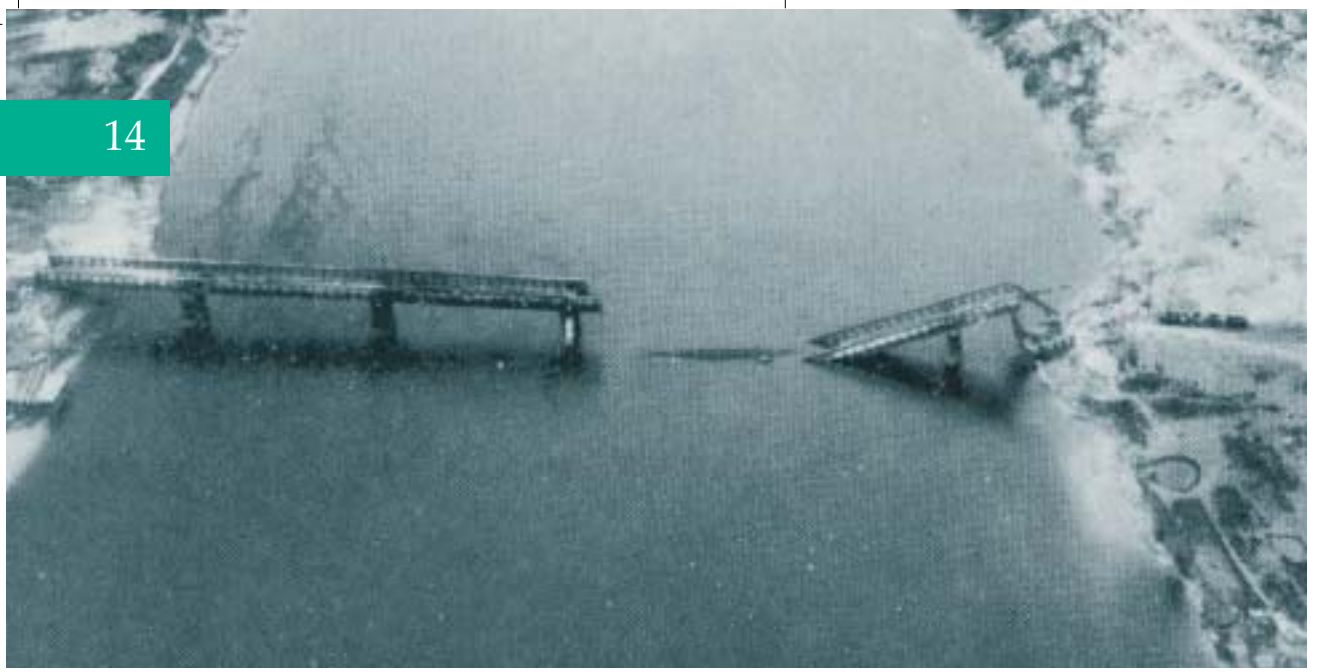
Before and after photographs of a marshalling yard at Juvisy near Paris, destroyed by RAF bombers

It took, on average, five times more bomb tonnage to stop trains by hitting marshalling yards than it did by hitting rail bridges

the traffic to keep flowing. It seems the Germans agreed: the officer in charge of the Italian Transport System later stated that marshalling yard attacks tended to destroy goods and rolling stock, but not the tracks themselves, which in any event were quickly repaired. The trains continued to run.[41]

In short, the desired effect was to stop trains, not put a certain percentage of bombs within a particular grid. Choosing the wrong measure of effectiveness (MOE) will defeat an EBO strategy. Although seemingly a fundamental consideration, it is regrettable how often such basics have been forgotten in air warfare.

I would also note, and this aside will no doubt resonate with modern air campaign planners, that the analysts at the EOU also argued that the bridges, usually located outside of urban areas, were less heavily defended and thus were less risky to the Allied aircrews attacking them. Moreover, this



In order to deliver a deathblow to German industry, and thus German military capability, the Allies had to stop the flow of coal. The best way to do this was by stopping the trains

location also meant there would be fewer civilian casualties and less collateral damage than if the bombers were going after marshalling yards—almost always located in city centers. Given that most rail targets—either bridges or marshalling yards—being struck in the months preceding and following OVERLORD were located in France, this was a major consideration. In fact, around 10,000 French civilians were killed in the marshalling yard strikes. At the same time, nearly 300 Allied bombers were lost attacking them. In contrast, Lytton argues that Allied losses were light when hitting bridges, as were casualties incurred by the French on the ground—although, suspiciously, he does not provide the statistics to back this up. Finally, it took, on average, five times more bomb tonnage to stop trains by hitting marshalling yards than it did by hitting rail bridges.

It would therefore seem that measures of effectiveness were crucial in determining targets for Allied bombers in World War II. If the goal was to put bombs efficiently on a target, then marshalling yards made a great deal of sense—it was difficult not to destroy *something* when 500 bombers dropped their loads on such a complex. On the other hand, if the objective was to stop trains, while also limiting casualties—both in the air and on the ground—then bridges made more sense, even if less efficient when measured in terms of bombs actually placed on target.

But the story is not quite over. To relieve some of the duplication and competition between the various groups of economic analysts, in October 1944 a new organization was formed, the Combined Services Targeting Committee (CSTC), which contained representatives from the RAF, AAF, MEW, EOU and COA. The benefit of creating yet another intelligence/planning agency was questionable. As the official history noted dryly: 'Neither of the two commanders [Spaatz and Harris] was prepared to accept the advice of the Committee except when he agreed with it.'[42] Nonetheless, ACM Tedder hoped to use this new analysis unit to help prod Spaatz—whose heart still belonged to oil—into a greater emphasis on rail targets. Although he had won the earlier battle over the oilmen, Tedder had seen his influence slipping ever since 14 September when the heavy bombers passed from Eisenhower's control (and hence his own) back to that of Harris and Spaatz. Initially, the bomber barons were not conducive to Tedder's urgings. After the first of the year, however, Tedder received unexpected support.

The Allies' breaking of German codes, transmitted by Enigma machines and whose products were referred to as Ultra intelligence, had been a fact since early in the war. We all know the vital importance of this special intelligence source. However, in January 1945 the German railroad system, which had been using its own teletype

network or telephone for transmitting its status reports, now began using Enigma. Hitherto, signals intelligence personnel had largely ignored rail traffic messages, believing them of little import, but when it began to use Enigma, they began to pay more attention—perhaps this was useful information after all.[43] By February 1945 the Enigma traffic finally revealed the crucial role that coal played in the German economy, powering virtually all industrial production. Indeed, 90 percent of all Germany's energy derived from coal: without coal, there was no German economy.

More to the point, this coal was moved around the *Reich* almost exclusively by train ever since Bomber Command had so thoroughly and effectively mined German rivers and canals, thus essentially eliminating all barge traffic.[44] Since the rail plan had been in effect, the movement of coal had slowed, causing serious negative effects on German production. The implication was clear. In order to deliver a deathblow to German industry, and thus German military capability, the Allies had to stop the flow of coal. The best way to do this was by stopping the trains.[45]

In essence, Tedder had been right all along, only for the wrong reasons. Neither he nor his planners had identified coal as the key commodity that made the *Reich* function. His plea in October 1944 for a major campaign against German rail lines (as opposed to those in France that had been the essence of the pre-invasion bombing plan) emphasized disrupting the flow of German reinforcements and supplies. The goal of this expanded rail campaign was to 'rapidly produce a state of chaos which would vitally affect not only the immediate battle on the West Wall, but also the whole German war effort.'[46] Coal was never even mentioned. Tedder was not, therefore, interested in studying intelligence related to its shipment. When his planners finally did so, almost by accident in February 1945, coal's importance quickly became apparent. But the evidence had been there all along. It merely required someone to establish coal as the crucial link, and then to identify the effect desired with an appropriate MOE—the halting of its movement by rail. Once this key relationship, desired effect, and metric were articulated, the bombing campaign could be focused on its achievement.

To illustrate the complexity of all this, let me add here that German coal officials apparently *welcomed* the Rail Plan that saw the focus of the Allied bombers move from targeting the Ruhr coal and steel district to marshalling yards in France and then Germany. Indeed, they saw the Rail Plan as a 'respite' that allowed them the opportunity to catch up in their coal *production* goals.[47] Of course, their objective was to produce coal, not to move that coal to where it could be used.

I would note one further item on this issue, one that highlights the serendipitous nature of war in so many instances. As mentioned above, the German rail system switched from its own teletype network and the use of telephones to the Enigma coding machine in early 1945, but this was not because anyone in the *Reich* hierarchy thought such information needed to be secured at such a high classification; rather, simply because Allied bombers had knocked out the teletype network, as well as most telephone lines and postal service. Had this not been the case, it is probable Enigma would never have been used, and the Allies would not have been curious enough to finally look into the movement of coal by rail.

Regarding the importance of an appropriate MOE, let me give another example from the World War II airwar. It was a prime dictate of airpower that air superiority was an absolutely crucial objective, and, indeed, soldiers and sailors realized this as well. As mentioned earlier, the gaining of air superiority prior to OVERLORD was an 'intermediate objective of overriding priority.' As General Eisenhower himself remarked, without air superiority there would have been no invasion.[48] But how does one measure air superiority? There are several possibilities: the number of enemy aircraft destroyed, on the ground or in the air; the number of Allied bombers shot down; the ability of the bombers to penetrate to their targets and effectively hit them; the number of enemy aircraft produced; the number of German aircraft operational at any given time; or the number of enemy sorties flown. All of these are useful and perhaps even

If 72,000 tons of bombs had been directed at the 65 targets comprising the German electrical power-generating network, that power grid would have been irreparably damaged. In short, if our intelligence had been better, 'the destruction of power generating and switch installations would have had a catastrophic effect on Germany's war production'....

important data points, but what was the appropriate MOE to measure air superiority?
A common criticism of the CBO and the air superiority campaign in particular was to note that the production of German single-engine fighters continued to rise throughout 1944, this despite the growing intensity of Allied bombing. If one were to use German production figures as the MOE for achieving air superiority, it would be logical to conclude that the air offensive was a failure. But was that the appropriate MOE?

We now know that there were large discrepancies between the numbers of aircraft allegedly produced and those actually delivered to operational *Luftwaffe* units.[49] In addition, the losses suffered by the *Luftwaffe* were so enormous, even increased production could not keep pace. As a consequence, by D-Day there were a mere 300 German fighters in France to oppose the 12,000 aircraft of the invading Allies. On the Eastern Front, *Luftwaffe* strength stood at 500 fighters, versus the Soviets' 13,000. Another 500 German fighters remained in Germany itself for air defense.

Did this connote Allied air superiority? In the first 24 hours of OVERLORD the Allies flew 12,015 sorties to 319 for the *Luftwaffe*.[50] Despite the statistics showing increasing fighter production, it was obvious that by D-Day the Allies controlled the skies. Clearly, German aircraft production figures were an inadequate test for determining the effectiveness of strategic bombing in general or the air superiority campaign in particular.

Let me add one other point here to further muddy the water. One of the key theorists and planners in the AAF was Brigadier General Haywood S. Hansell. He had been an instructor in the Bombardment Section at the Tactical School in the 1930s, had helped write AWPD-1, the AAF's first airwar plan for Germany, and had also participated in writing the Casablanca Directive. Hansell was not just a desk general. In 1942 and 1943 he served as a bomb wing and then bomb division commander in the Eighth Air Force; the following year he was given command of the B-29s in the XXI Bomber Command based on Guam. More than two decades after the war Hansell wrote of his experiences and, buttressed by the US Strategic Bombing Survey, opined that the Allied bombers made a mistake in not attacking German electricity.

Although this was always seen as an important aspect of the German industrial infrastructure, it was also seen as a poor target because of its small and dispersed nature. Not so, said Hansell in 1972. If 72,000 tons of bombs had been directed at the 65 targets comprising the German electrical power-generating network, that power grid would have been irreparably damaged. This tonnage, Hansell added, would have been in addition to that dropped on oil, which he also regarded as crucial. In short, if our intelligence had been better, 'the destruction of power generating and switch installations would have had a catastrophic effect on Germany's war production.'[51]

Who was correct in all of this? Was there a key node that should have been concentrated on by the heavy bombers? At various times there were several contenders for this magic bullet: oil, coal, rail lines, electricity, and ball bearings. Were these truly key, or were they mere 'panacea targets' as Arthur Harris suggested? In his view, the Germany economy was so large, so complex, and so redundant that only a wholesale destruction of the *entire* economy would bring Germany to its knees. In this view, strategic bombing was a *process*, not an event—persistence was essential.

It is useful to ask what the Germans thought of the Allied air offensive's importance. Albert Speer, the German Minister of Armaments and War Production later wrote:

I shall never forget the date May 12, [1944] . . . On that day the technological war was decided. Until then we had managed to produce approximately as many weapons as the armed forces needed in spite of their considerable losses. But with the attack of nine hundred and thirty-five daylight bombers of the American Eighth Air Force upon several fuel plants in central and eastern Germany a new era in air war began. It meant the end of German armaments production.[52]

On the other hand, that same November he wrote Hitler regarding the bombing attacks on the Ruhr that focused on rail lines:

We are on the verge of the most serious coal production crisis since the beginning of the war. . . . For more than six weeks now, in the matter of transport the Ruhr has become more and more cut off from the areas it supplies. . . . It is clear from Germany's overall economic structure that in the long run the loss of the industrial area of Rhineland-Westphalia would be a mortal blow to the German economy and to the conduct of the war.[53]

To confuse things further, when Speer was interrogated on July 18, 1945, he stated that the crucial targets the Allies should have bombed more vigorously were chemicals, ball bearings and electrical power, implying these target systems were more important than either oil or coal.[54]

It would seem that not only were Allied planners and analysts uncertain as to what was going on in the German economy, but the head of German armaments production was similarly confused regarding the status of his empire. I would add on a lighter note that Speer was often surprised by the Allies' inability or unwillingness to follow up on air attacks that he thought had been particularly devastating: 'We have a powerful ally in this matter, that is to say that the enemy has an Air Force general staff as well.'[55]

To summarize the World War II experience: although EBO was at the root of what airmen hoped to achieve through airpower, going into the war air planners had no real precedents for determining appropriate objectives, targets and MOEs for strategic bombing. At the same time, they had almost no experience with gathering the types of intelligence necessary to conduct such a campaign. These two processes, both of which required massive resources and conceptual skill, had to be created from scratch. Because targets and intelligence had a symbiotic relationship to each other, it was an unusual phenomenon that at times the intelligence gathered shaped the choice of targets; whereas, on other occasions the opposite was true. Many mistakes were made along the way, but we should not underestimate the importance and difficulty of conceptualizing and then creating not only an entire economic intelligence apparatus that had not previously existed, but also a methodology and process—though rudimentary by today's standards—on how to plan and conduct an economic warfare air campaign.

Following World War II things at once both got better and worse for EBO advocates. Strategic Air Command (SAC) and its bomber fleet carrying nuclear weapons, eventually joined by nuclear-tipped ICBMs, formed an enormous organization, the Joint Strategic Target Planning Staff (JSTPS), to study the Warsaw Pact's economic and military structures. This highly secretive body, most of which operated several floors below the ground at SAC headquarters at Offutt AFB, Nebraska, had access to the sensors, intelligence sources and analysts to conduct an in-depth study of the Warsaw Pact. It was the EOU and COA writ very large. Unfortunately, the emphasis on the Soviet Union, as well as the reliance on nuclear weapons, made the JSTPS of limited utility when conventional wars broke out in Korea and Vietnam.[56]

When the US entered the Korean War, air planners were intent on repeating their success of World War II in Europe. Although true strategic targets in China and the Soviet Union were off limits, rendering the detailed nuclear studies irrelevant, airmen believed they could at least so isolate the North Koreans (and later Chinese) forces as to make them harmless. As a consequence, the USAF launched a series of interdiction campaigns with impressive codenames like STRANGLE, STRANGLE II, and SATURATE. An enormous amount of effort was funneled into these campaigns—around 50 percent of all USAF combat sorties during the war were interdiction.

The divided responsibility for selecting, planning, and conducting operational air strikes meant that targets, at least as far as the airmen were concerned, were divorced from the political and military objectives sought

When Navy and Marine sorties are included, the US flew over 320,000 interdiction sorties during the war—on average nearly 9,000 per month.[57] What were the results of this massive effort? If the effect desired was destruction of enemy equipment, then the results were impressive indeed. By the end of the war airmen of all three services claimed they had destroyed or damaged a total of 5,087 bridges, 2,345 locomotives, 41,882 rail cars, and 111,623 vehicles.[58] Even assuming there was a certain amount of exaggeration in these claims, one could certainly expect that the communist forces would have been virtually immobilized if not completely disarmed by such destruction. The actual results were different. In July 1951 the enemy fired around 8,000 artillery rounds at United Nations forces; less than a year later—after ten months of concentrated air interdiction—they were able to fire over 100,000 rounds.[59]

Clearly, something was very wrong. The old bugbear of the previous war—determining a reliable and useful measure of effectiveness—had returned with a vengeance. If the MOE was destruction of equipment, the number of sorties flown, or the tonnage of bombs dropped, then air interdiction was a tremendous success. If the MOE was, however, the ability of the enemy to fight, the conclusion was far different. This same problem continued throughout the next 'minor war' in Asia.

During the Vietnam War it was common to criticize the US Army for its 'body count' mentality. This was the epitome of an MOE gone wrong. But airmen were just as guilty. Vietnam became an exercise in counting—sorties, bomb tonnage, jungle trails cut, trucks destroyed, bridge spans dropped and water buffalo killed—water buffalo could be used for transport. As so often occurs in such situations, the drive to gather data and indeed to *generate* data became an end in itself. As a result, although there was a severe bomb shortage in the early years of the airwar, planes were sent out anyway, sometimes with only one or two bombs. A sortie was, after all, a sortie, and The Graph must not show a decline—especially relative to the US Navy.[60]

Virtually all targets struck by air in South Vietnam were selected by the staff at Military Assistance Command Vietnam (MACV). This largely US Army organization had only token USAF representation, despite the fact that the Seventh Air Force commander, a USAF four-star general, was nominally designated MACV's 'deputy for air.' Because the Army selected all targets based on a ground situation they alone saw, the MOEs for the air strikes were not clear. Airmen therefore invented their own: the army wanted a target struck, and if it was, the mission was declared a success.

Key yardsticks were aircraft readiness rates, tons of ordnance dropped, the rapidity of response, and sortie rates. In essence, the task of the USAF was merely to service a list of targets for the Army. The MOE thus became a determination of how quickly, effectively, and efficiently airmen were able to service that list. The divided responsibility for selecting, planning, and conducting operational air strikes meant that targets, at least as far as the airmen were concerned, were divorced from the political and military objectives sought. If such a causal link was actually made, it was done by MACV, the keeper of the target list, not Seventh Air Force. EBO was non-existent. As one historian phrased it: 'An enormous quantity of data described the Air Force's effort, but little its progress, in South Vietnam.'[61]

The problem of counting things and mistaking that for effectiveness was true regarding the airwar over North Vietnam as well. For example, after the Linebacker II strikes of December 1972, the USAF stated that the North Vietnamese rail yards had suffered the greatest amount of damage of all the targets struck: 'a damage level of 60 percent or better was achieved against two-thirds of the railroad yard targets representing damage to

USAF B-52 bomber

Today, the USAF has over 2,500 fighter planes, but only 208 bombers; moreover, it is likely the number of bombers will decrease further in the years ahead

the most important rail facilities, other than bridges, in North Vietnam.' The study is mute, however, on whether or not this level of damage had any effect on the shipment of supplies or armaments to North Vietnamese forces. Moreover, the study also notes that because of earlier air strikes most traffic had already been moved from rail to roads.[62] In short, what was the effect desired—to limit movement of military supplies, or simply to destroy marshalling yards and rolling stock? If the former, then the air strikes were ineffective, regardless of the amount of damage allegedly produced. Just because you can count something does not mean it is important.

The core issue, as it had been in World War II, revolved around MOEs. The real goal of the US was to stop the communist insurgency in the South and to ensure a safe and democratic regime there. In order to accomplish these goals the Viet Cong insurgents had to be eradicated and/or their supply of troops, ammunition and equipment from the North must be eliminated. If those were the military goals that would fulfill the political mandate, then all of the data points noted above seemed to have some relevance, but as always, the key question remained: which MOE(s) was the true criterion that would indicate if the American strategy was succeeding or failing? SAC's targeting body might have been able to shed some light on this, but as noted, they were preoccupied. Even so, it is unfortunate that at least some of the processes, methodologies and models used at Offutt were not adapted for use in a conventional war.

Following the Vietnam War the US Air Force underwent a fundamental reorientation. The doctrine of strategic airpower, at least as represented by nuclear weapons, increasingly receded to the background. So too did the bomber pilots who had held most of the key leadership positions

within the service for several decades. Fighter pilots, who had borne the brunt of the war in Vietnam, now took over most of the top slots in the USAF. The backbone of the air fleet, which had been the heavy bombers and ICBMs of SAC, similarly decreased dramatically in numbers and importance. Today, the USAF has over 2,500 fighter planes, but only 208 bombers; moreover, it is likely the number of bombers will decrease further in the years ahead.[63]

The lights were out in Baghdad, and indeed throughout most of Iraq. Wasn't that the effect desired? What did it matter how many smoking holes there were across Iraq? Clearly, the bombing of electricity had been virtually 100 percent effective

One of the important results of this fundamental organizational, structural and doctrinal shift was the recognition of the importance of strategic conventional air operations. Airpower's unique ability to operate at the strategic level of war immediately upon the outset of hostilities was still a fact, even if airmen had given it little thought for the previous three decades. Two men, both USAF fighter pilots, led the intellectual journey back to serious thinking about air strategy.

It is not my place here to discuss either the lives or theories of John Boyd and John Warden; rather, it is to point out that both men moved away from a concept of air strategy that had focused on an enemy's economy, but instead to focus on his leadership. This is not to say that either man eschewed the targeting of an enemy's industrial or economic infrastructure—there were often sound reasons to continue to neutralize such targets. Instead, the focus was to be on the leadership—what made them capable of coercion? In some cases the attack against a particularly important industry might have a powerful impact on the mind of the leadership. In other cases, an attack on the leaders themselves, even if unsuccessful, might still prompt a desirable change in behavior. For advocates of EBO, this shift in targeting strategy introduced new problems. A leadership or coercive strategy is far more dependent on cultural, psychological, religious or political factors than one that is focused on the economy. If the goal is to shut down an economy, then it is possible, sometimes, to measure the results of an air strike on a power grid, rail network or communications system. But how does one measure the coercive effect of hitting such targets—or any others—on the mind of a nation's leaders? The main problem with EBO in World War II, and to some extent today, lies mainly in the realm of predicting human behavior in a crisis. EBO had tremendous difficulty in dealing with uncertainty, randomness, chance, and the non-linear and often seemingly irrational thinking of human organisms. Quite simply, different people don't respond the same way to the same stimuli. In fact, some people respond differently to the same stimuli at different times.

This may perhaps be due to the learning of lessons, fatigue, or a host of other circumstances that have subtlety yet decidedly changed the equation in that individual's mind. In any event, human behavior, especially when under pressure or when operating from a different cultural mindset, is incredibly difficult to predict. Remember too that our adversaries at the same time are doing everything in their power to mask their true intentions from us. In short, EBO moved into an even more nebulous and complex area than it had been in previously, and yet, we have not completely solved the problems of measuring effects in an economic model!

By the Persian Gulf War in 1991, EBO had become increasingly ingrained in the minds of key airmen. Then-Lieutenant Colonel Dave Deptula tells of

how initial air plans called for each Iraqi air defense sector control center to be targeted by eight F-117s to ensure their destruction. This would have required a great deal of sorties for the high-demand stealth fighter-bombers. Deptula then postulated that a single bomb would no doubt shut down operations physically, while also causing any technicians still alive inside to flee. The number was then reduced from eight sorties per facility to two.[64] The desired *effect* was to shut down the air defense system; total destruction was therefore not necessary.

Not well known nor reported is that EBO was the underlying basis for the design of the entire Gulf War air campaign. Deptula built the air attack plans for each 24-hour period of the war. He established desired effects criteria for each of the designated 12 target sets and formulated each day's air attack plan on the basis of progress measured in achieving those effects for each target set; he then watched to ensure the plans and the attacks were interacting properly to accomplish the overall campaign objectives. Not everyone was on board, however.

John Warden tells the story of talking to intelligence analysts who assigned BDA figures to specific target sets. Regarding the strikes against electricity during the first few days of the war, the analyst gave a BDA assessment of 10 percent effective—not an impressive figure. When Warden asked why he had given such a low estimate, the analyst replied that there were a specified number of electrical power plants in Iraq, and Coalition bombs had only destroyed 10 percent of them. The arithmetic was pretty simple. Warden remonstrated that the lights were out in Baghdad, and indeed throughout most of Iraq. Wasn't that the effect desired? What did it matter how many smoking holes there were across Iraq? Clearly, the bombing of electricity had been virtually 100 percent effective! The analyst hung up.[65]

At the broadest sense, the primary objective of the Coalition was to liberate Kuwait quickly and with minimum loss of life. Regrettably, the MOE for this desired effect rapidly devolved down to counting tanks and artillery pieces destroyed from the air. Debates still rage over how much Iraqi equipment was actually destroyed and by whom, but this fuss misses the point. The objective was to get the Iraqi army out of Kuwait: because of the air campaign, over 80,000 Iraqi soldiers deserted and a like number surrendered virtually without a fight. Coalition losses were 240 killed and less than 800 wounded.[66] This was EBO at its most impressive.

The debate over air strategy today remains what it has been for the past century, an argument over targeting. The main thrust of air theory over that period focused on an economic theory of war. Airpower was seen as a more direct and more rapid form of traditional sea power—although I doubt if many airmen or sailors would ever admit that. This concept is still with us. For example, General Michael Short, the air commander in the airwar over Serbia in 1999, has argued that air strikes on the first night of the war should have concentrated on the critical infrastructure of Belgrade: the power grid, bridges over the Danube, and key factories.[67] These targets should have been quickly and precisely destroyed. An instructor at the Air Corps Tactical School or the RAF Staff College in 1935 would have said much the same thing.

There have been, however, important variations over time. Some, like Arthur Tedder in World War II, focused on an enemy's transportation system so as to produce paralysis. More than a decade ago John Boyd and John Warden instead looked at leadership. In a sense, their goal was also paralysis. In addition, some, like political scientist Robert Pape and non-airmen like US Army generals Wesley Clark and Gordon Sullivan, have argued that wars are won the old fashioned way—by killing armies; only today airpower can kill armies faster and with less risk than armies can kill armies.[68]

In sum, the natural tendency of planners and analysts to count things, although necessary at the tactical level, has severe limitations as a strategic MOE and can indeed distort the entire strategy/planning process. There must be a method of translating 'statistical destruction' into a broader strategic context. If such a method is not devised, then it will be easy to fall into the trap of

being efficiently ineffective—of destroying targets that don't matter.

The linchpin of EBO revolves around developing the most appropriate MOEs. The combatant commander and his component commanders must think this issue through and must do so with open minds. They must also recognize that EBO is an iterative process—desired effects and MOEs selected one day may be wrong or may change later in the war as conditions or intelligence appraisals change. Unfortunately, there is a tendency in war either to select MOEs based on traditional methods of war that may no longer apply—an attrition-based model; or, MOEs are allowed to become fossilized and unchangeable—to adjust an MOE or a strategy signals that mistakes were made earlier. No one wants to admit they made potentially serious errors. But when this happens, it's best to recall the old saying: when you find yourself in a hole, stop digging.

EBO is an inherently rational way to approach war. Yet the barriers to making it work are formidable. Although our analytical tools have improved dramatically over the years, it often seems as if we are peeling an onion; as we remove one layer of problems and questions, it merely leads to several more layers. Many challenges still remain: the need for adequate intelligence of various kinds, our distressing lack of cultural sensitivity regarding potential adversaries, the dangers of studying inputs rather than outputs, and the need for models and simulations that adequately account for cognitive, cultural, political and social factors. These are serious problems, but for too long military commanders and planners have hidden behind the 'fog of war' argument—that war is so imponderable and freighted with friction and uncertainty we cannot hope to rationalize it.

Such an attitude is no longer acceptable. The bar has been raised not only for airmen, but for soldiers, sailors and marines as well. To borrow a metaphor from music, the modern strategist who understands and masters EBO has the potential of being a conductor: orchestrating a complex symphony of actions that achieve the desired effects of harmony and music—success in war—rather than the noise of wanton violence.
Airmen have always hoped to achieve EBO. For much of the first century of air warfare that goal was beyond their reach, due both to the technological limitations of aircraft and weapons, but also because of inadequate intelligence and analytical tools. The tools and technology are catching up. Think of the possibilities.

Notes:

1 Paul K. Davis, *Effect-Based Operations: A Grand Challenge for the Analytical Community* (Santa Monica: RAND, 2001), 7.

2 Maurer Maurer, *The U.S. Air Service in World War I*, 4 vols. (Washington: Office of Air Force History, 1978), II, 141-57 reprints the Gorrell memo in its entirety.

3 William L. Mitchell, *Winged Defense: The Development and Possibilities of Modern Air Power, Economic and Military* (NY: Putnam's, 1925), 126-27.

4 Giulio Douhet, *The Command of the Air* (NY: Coward-McCann, 1942; reprinted by the US Air Force History Office in 1983), 20.

5 Ibid., 50.

6 US Army Field Manual, 1-5, 'Employment of Aviation of the Army,' April 15, 1940, 11, 36.

7 Royal Air Force Manual AP 1300, 'War Manual,' February 1940, chap. 6, p. 12.

8 Two examples from many: J.F.C. Fuller, *The Reformation of War* (London: Hutchinson, 1923), 150; and L.E.O. Charlton, *War from the Air: Past, Present, Future* (London: Thomas Nelson, 1935), 172-73.

9 Thomas H. Greer, 'The Development of Air Doctrine in the Army Air Arm, 1917-1941.' Air Force Historical Study No. 89, Maxwell AFB, 1955 (reprinted by the Office of Air Force History, 1985), 81.

10 Stephen L. McFarland, *America's Pursuit of Precision Bombing, 1910-1945* (Washington: Smithsonian Institution Press, 1995), 93-98.

11 Guido R. Perera, *Leaves from my Book of Life, Vol. II: Washington and War Years* (Boston: Privately Printed, 1975), 71.

12 'War Diary,' R&A Branch, OSS London [Enemy Objectives Unit], 1945, AF Historical Research Agency (AFHRA) file 520.056-167, 42; 'History of the Committee of Operations Analysts,' 1945, AFHRA file 118.01, 35.

13 Perera, 99. Perera states that he met his coldest reception from the AAF intelligence section in Washington. Upon paying a courtesy call to the Director, Major General Clayton Bissell, he was quickly informed: 'I have quite a file on you here in my desk, and I want you to understand that I don't want any nonsense in the future.'

14 Wesley Frank Craven and James Lea Cate, *The Army Air Forces in World War II*, 7 vols. (Chicago: University of Chicago Press, 1948-58), II, 369.

15 F.H. Hinsley et. al. (eds.) *British Intelligence in the Second World War*, 5 vols. (London: HMSO, 1970-1990), III/1, 54; COA History, 28, 52.

16 Alan S. Milward, *War, Economy and Society, 1939-1945* (Berkeley: University of California Press, 1977), 298.

[17] Richard J. Overy, *Why the Allies Won* (London: Jonathan Cape, 1995), 203.
[18] Craven and Cate, II, 358.
[19] US Strategic Bombing Survey (USSBS), 'Over-All Report (European War),' February 1947, 39-40. Another process, Fischer-Tropsch, was also used, but hydrogenation remained by far more important while also providing all of the *Reich's* synthetic aviation gasoline. Indigenous sources plus synthetic fuels still only provided Germany with about 1/3 of its necessary fuel supplies.
[20] Stephen Rosen, *Winning the Next War: Innovation and the Modern Military* (Ithaca: Cornell University Press, 1991), 161-63. USSBS, 'Over-All Report,' 39, states that Germany had only 1.6 million tons of fuel in reserve at the start of the war—less than six months supply of wartime requirements. However, this figure actually grew over the next several years despite the demands of military operations, because Germany captured more refineries and hence more fuel than they consumed.
[21] COA History, 43; EOU 'War Diary,' 36-37. The EOU diary also includes the factor of risk to Allied aircrews—an important consideration, as planners would certainly attest today. See also Walt W. Rostow, *Pre-Invasion Bombing Strategy* (Austin: University of Texas Press, 1981), 99-104; Mancur Olson, Jr., 'The Economics of Target Selection for the Combined Bomber Offensive,' *Royal United Services Institute Journal*, CVII(November 1962): 308-14.
[22] EOU 'War Diary,' 43-46. Nonetheless, sub pens were a top priority for the CBO, largely because the Battle of the Atlantic was so crucial to Allied success. All efforts, even those of marginal utility, had to be expended to reduce the U-boat menace. For its part, the AAF saw the sub pen missions as relatively easy—almost training missions—because the location of the pens along the French coast allowed fighter escort.
[23] EOU 'War Diary,' 22-33.
[24] Sir Charles Webster and Noble Frankland, *The Strategic Air Offensive Against Germany, 1939-1945*, 4 vols. (London: HMSO, 1961), IV, 205-13.
[25] COA History, 20. In Britain, RE 8, a department in the Ministry of Home Security, handled the bomb damage assessment task. For the fairly dismal accuracy of the Eighth Air Force, although it did improve greatly over time, see USSBS, 'Bombing Accuracy, USAAF Heavy and Medium Bombers in the ETO,' January 1947.
[26] Perera, 139; USSBS, 'The German Anti-Friction Bearings Industry,' November 1945, 1, 31, 38.
[27] For an excellent discussion of how the formulation of measures of merit can affect strategy, see Scott S. Gartner, *Strategic Assessment in War* (New Haven: Yale University Press, 1997).
[28] EOU 'War Diary,' 39.
[29] Craven and Cate, II, 305.
[30] Craven and Cate, II, 665.
[31] MRAF Sir Arthur Harris, *Bomber Offensive* (London: Collins, 1947), 223. See his entire chapter 10 for a spirited denunciation of 'panacea targets.'
[32] Much has been written on the oil/rail plan controversy. For the official histories see Craven and Cate, III, 42-64; Webster and Frankland, III, 42-64; Lord [Arthur] Tedder, *With Prejudice* (Boston: Houghton Mifflin, 1966), 513-24; Solly Zuckerman, *From Apes to Warlords* (NY: Harper & Row, 1978), chapter 12; and, Rostow, 88-98, which includes the complete minutes of the climactic meeting of 25 March.
[33] USSBS, 'Oil Division Final Report,' August 1945, 2, 43-46. Of interest, the COA submitted a report in December 1943 identifying the five TEL plants in the *Reich*, concluding: 'It is believed they are good targets.' Apparently, their suggestion was ignored. COA History, Tab 7.
[34] USSBS, 'Oil Division Final Report,' 1, 3; Burton H. Klein, *Germany's Economic Preparations for War* (Cambridge: Harvard University Press, 1959), 226; Rosen, 165.
[35] Zuckerman, 209-10, 220-23.
[36] Craven and Cate, III, 371-73; James Parton, *'Air Force Spoken Here': General Ira Eaker and the Command of the Air* (Bethesda: Adler & Adler, 1986), 380-83; MRAF Sir John Slessor, *The Central Blue: Recollections and Reflections* (London: Cassell, 1956), 567-77. Slessor was Eaker's deputy in the Mediterranean Allied Air Forces.
[37] EOU 'War Diary,' 101.
[38] For a thorough discussion see Zuckerman, chapter 12; Rostow, chapter 8; and Richard G. Davis, *Carl A. Spaatz and the Air War in Europe* (Washington: Smithsonian Institution Press, 1992), 403-08. For the caustic response of Harris to Zuckerman's plan see Henry Probert, *Bomber Harris: His Life and Times* (London: Greenhill, 2001), 291-92.
[39] This exchange of letters appeared in three issues of *Encounter*: 51(November 1978): 39-42; 52(July 1979): 86-89; and 53(August 1980): 100-02.
[40] Henry D. Lytton, 'Bombing Policy in the Rome and Pre-Normandy Invasion Aerial Campaigns of World War II: Bridge-Bombing Strategy Vindicated—and Railyard Bombing Strategy Invalidated,' *Military Affairs* 47(April 1983): 53-58. Lytton's title pretty much says it all.
[41] F.M. Sallagar, 'Operation 'STRANGLE' (Italy, Spring 1944): A Case Study of Tactical Air Interdiction,' RAND Study R-851-PR, February 1972, 33.
[42] Webster and Frankland, III, 216.
[43] Alfred C. Mierzejewski, *The Collapse of the German War Economy, 1939-1945: Allied Air Power and the German National Railway* (Chapel Hill: University of North Carolina Press, 1988), 167-69.
[44] Around 60 percent of the oil from Rumania was transported to Germany via barge on the Danube River. When the RAF mined the Danube it brought this traffic to a halt. When it is realized that one barge of oil was equivalent to a 100-car train, it is obvious how important these mining operations were in throttling Germany's oil supply. Robert Goralski and Russell W. Freeburg, *Oil and War: How the Deadly Struggle for Fuel in World War II Meant Victory or Defeat* (NY: Morrow, 1987), 271; Ronald

C. Cooke and Roy C. Nesbitt, *Target: Hitler's Oil, Allied Attacks on German Oil Supplies, 1939-1945* (London: William Kimber, 1985), 70.

[45] This entire argument is spelled out in detail in Mierzejewski.

[46] Webster and Frankland, IV, 290-92, contains the entire text of Tedder's 'Note on Air Policy to be Adapted with a View to Rapid Defeat of Germany,' dated October 25, 1944. It is also interesting that in neither the COA nor EOU histories is coal ever once mentioned as a possible target.

[47] John Gillingham, *Industry and Politics in the Third Reich: Ruhr Coal, Hitler and Europe* (NY: Columbia University Press, 1985), 113. Contrary to Mierzejewski, Gillingham (pp 124-29) argues that the real problem with the German coal industry during the war was a severe labor shortage in the mines: coal *production* was collapsing long before the railroads were disrupting its distribution. This is just another example of how the sources a historian examines will, to a great extent, determine his conclusions.

[48] Before Congress in 1945, Eisenhower stated that undertaking OVERLORD without air superiority 'would have been more than fantastic, it would have been criminal.' Testimony of Gen Dwight D. Eisenhower, to Senate, Departments of Armed Forces and Military Security, *Hearings Before the Committee on Military Affairs*, 1945. 79th Congress, 1st session, 1945, 360.

[49] US Strategic Bombing Survey, 'Over-all Report (European War),' 18-22.

[50] Overy, 124; John Keegan, *Six Armies in Normandy* (NY: Viking, 1982), 143.

[51] Haywood S. Hansell, Jr., *The Air Plan that Defeated Hitler* (Atlanta: Higgins-McArthur, 1972), 286-97; USSBS, 'German Electric Utilities Industry,' October 1945, 1-3.

[52] Albert Speer, *Inside the Third Reich* (NY: Macmillan, 1970), 346.

[53] Webster and Frankland, IV, 349-56, has the complete text of Speer's letter to Hitler of November 11, 1944. Note that Speer refers to a coal *production* crisis, not a coal *transportation* crisis. Is he implying it was not a rail problem after all?

[54] Webster and Frankland, IV, 384.

[55] Klein, 119.

[56] One of the classic examples of EBO air operations during the Cold War was the Berlin Airlift. The Allied goal was to save West Berlin from starving, freezing, or caving in to communist aggression. The 11-month Airlift to deliver food and coal to the beleaguered Berliners was enormously successful at achieving those policy goals, and did so without firing a shot.

[57] Edmund Dews and Felix Kozaczka, 'Air Interdiction: Lessons from Past Campaigns,' RAND Note N-1743-PA&E, September 1981, 49-51.

[58] Ibid., 55. One of the reasons for the disconnect between the supposed destruction results and the enemy's actual military capability was due to mirror imaging. A US Army division required around 500 tons of supplies daily to sustain itself: a Chinese or North Korean division required only 48 tons. Even if interdiction was stopping 90 percent of supplies flowing south, the 10 percent that got through was enough to keep the enemy going. Gregory A. Carter, 'Some Historical Notes on Air Interdiction in Korea,' RAND Note P-3452, September 1966, 4.

[59] Dews and Kozaczka, 57.

[60] John Schlight, *The USAF in Southeast Asia. The War in South Vietnam: The Years of the Offensive, 1965-1968* (Washington: Office of Air Force History, 1988), 69, 78, 154, 190.

[61] Ibid., 290.

[62] Pacific Air Forces, 'Linebacker II USAF Bombing Survey,' April 1973, 5-6.

[63] 'World Military Aircraft Inventory,' *Aviation Week & Space Technology*, January 13, 2003, 274-75.

[64] Brig Gen David A. Deptula, 'Effects-Based Operations: Change in the Nature of Warfare,' Aerospace Education Foundation paper, 2001, 12.

[65] John Warden, 'The Enemy as a System of Systems,' presentation to the Swedish National Defence College, Stockholm, January 27, 2003.

[66] Eliot Cohen (ed.) *Gulf War Air Power Survey*, 5 vols. plus *Summary* (Washington: GPO, 1993), *Summary*, 105-06; Lawrence Freedman and Efraim Karsh, *The Gulf Conflict, 1990-1991: Diplomacy and War in the New World Order* (Princeton: Princeton University Press, 1993), 409.

[67] Interview with General Michael C. Short, 'War in Europe: NATO's 1999 War against Serbia over Kosovo,' PBS, February 2000, website: http://www.pbs.org/wgbh/pages/frontline/shows/kosovo/.

[68] Robert Pape, *Bombing to Win: Air Power and Coercion in War* (Ithaca: Cornell University Press, 1996), passim; Gen Gordon R. Sullivan, 'Lessons That Still Apply,' *Washington Times*, March 3, 2001, A31; Gen Wesley K. Clark, *Waging Modern War: Bosnia, Kosovo and the Future of Combat* (NY: PublicAffairs, 2001), passim, but especially 221, 241-42, 425.