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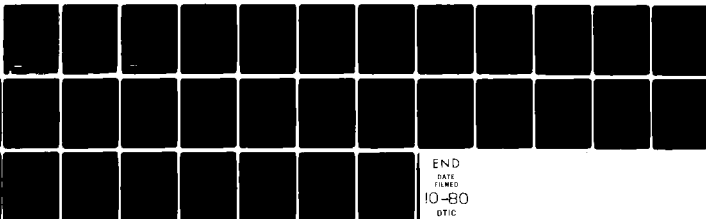
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A RAND NOTE

NATO INLAND TRANSPORT AS A POTENTIAL REAR-AREA TARGET SYSTEM: LESSONS FROM GERMAN EXPERIENCE IN WORLD WAR II

Edmund Dews

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PREFACE

This Note provides a brief analytical review of the results of World War II Allied air attacks against the German waterway and rail transportation systems--two of the many different target systems now being examined in a study of possible vulnerabilities in NATO's rear areas.

The objectives of the larger study are to determine what NATO facilities and activities in the Central Region rear might be attacked by Warsaw Pact airpower in the early days of a nonnuclear conflict, to estimate how the Pact might allocate its airpower to these target systems under different warning and mobilization assumptions, and to illuminate any requirements for additional measures to reduce target vulnerability. The research for the present Note and for the larger study which it supports was sponsored by the Office of the Assistant Secretary of Defense, Program Analysis and Evaluation.

The present Note describes the effects of different types of air attacks against the German waterways and railroads in World War II, and raises questions concerning the possible vulnerabilities of these two systems in the 1980s. Although focused on possible NATO vulnerabilities, the conclusions of this Note appear to have wider application--for example, in assessing the vulnerabilities of Warsaw Pact transportation systems.

The Note is based on published sources, particularly the detailed reports of the United States Strategic Bombing Survey, which assembled and analyzed German data and interviewed German officials at the end of the war.

SUMMARY

During the first four years of World War II, the transportation systems inside Germany were not high priority targets for Allied air attack. In September 1944, however, the Allies moved German transportation near the top of the priority list for strategic air attack, and at about the same time a substantial number of tactical air sorties were committed against targets inside Germany. Both the waterway and railroad systems were attacked. The results were significant and began to be felt almost immediately.

Against river traffic the most effective measures were the dropping of bridge spans and the laying of shallow-water mines. The dropping of the suspension bridge at Cologne and the seeding of the Danube with mines had truly spectacular results in reducing river traffic.

Against canal traffic the most effective measures were the breaching of canal walls and, again, the dropping of bridge spans. Canal walls made of earth were breached where the water level was above that of the surrounding countryside; the escaping water created large gaps that took weeks to repair; and the loss of water drained long stretches of canal and made them inoperable. By attacking some of the critical links in the canal system, the Allies put much of it out of action and threw a heavy burden on the railroads.

In spite of this clear-cut success in the attacks against inland waterways, the United States Strategic Bombing Survey (USSBS) concluded after the war (on the basis of careful studies of actual target damage) that a much more efficient job could have been done. If the best targets had been concentrated on (particularly some of the nodal canal locks and the suspension bridges over the Rhine), all the important north German canal traffic and through traffic on the Rhine could have been stopped much earlier in the war and with far fewer sorties.

The rail system was much more complex and extensive than the waterways, and had greater redundancy and flexibility. For the first four years of the war it effectively fulfilled German military and economic

needs, and was regarded by the Minister of Transport as "crisis proof." However, within a month after the air campaign against transportation began in September 1944, rail traffic began to be seriously delayed: the railroads' ability to meet military demands was definitely impaired in terms of both strategic movements across Germany and tactical deployments in the West, although military traffic was given absolute priority. The crippling of rail transport was reflected in both the delayed timing of the Rundstedt offensive in the Ardennes (the Battle of the Bulge) and the inadequate logistic support provided to the German forces involved.

The success of the air campaign against German rail transportation was due more to brute force than skill in the selection of targets, if the USSBS assessment is correct. In particular, the attacks against marshalling yards appear to have had little immediate effect on military traffic, although, when repeated frequently with massive numbers of heavy bombers, they helped to cripple the war economy and ultimately made a substantial contribution to the collapse of the rail system in the spring of 1945.

According to the USSBS analysis, *the preferred rail targets were the rail lines themselves, especially where they could be cut by attacks against bridges, viaducts, and underpasses.* If such features were not present, attacks against track sections in open country or at the entrances to stations or yards were also effective. But a careful selection of suitable links to be attacked was seen as necessary for a successful line-cutting strategy.

In order of preference after line cuts, the USSBS identified the following target types: (a) rail telecommunications and signal equipment, (b) servicing and repair facilities, and (c) rolling stock. Locomotives and rail cars would no doubt have had a higher priority if they had been in short supply, but by 1944 there was a surplus of all kinds of rolling stock within Germany. Although not stating so explicitly, the USSBS apparently regarded marshalling yards as at or near the bottom of the list.

CONTENTS

PREFACE	111
SUMMARY	v
Section	
I. INTRODUCTION	1
II. ATTACKS AGAINST WATERWAYS AND WATERWAY TRAFFIC	3
The Waterway System	3
Watercraft as Targets: Modest Results in the Northwest	3
The Danube Campaign: Air-Delivered River Mines Highly Effective	4
Destruction of Bridges Over Canals and Rivers	5
Breaching Canal Walls	6
Observations and Conclusions	8
III. ATTACKS AGAINST THE RAIL SYSTEM	10
The Rail System	10
Strafing Attacks Against Locomotives and Rolling Stock	12
Bombing Attacks Against the Fixed Elements of the Rail System	13
Marshalling Yards	14
Railway Signals, Telecommunications and Electric Power	16
Rail Lines	17
Preparations for Repair; Repair Times	19
Accuracy of Allied Bomb Damage Assessment	20
Effects of Rail Attacks on Military Movements	21
Observations and Conclusions	23
REFERENCES	27

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Prepared as background material in support of a study of possible vulnerabilities in NATO's rear areas, this Note provides a brief analytical review of the results of World War II Allied air attacks against the German waterway and rail transportation systems. It describes the types of attacks against the waterways and railroads, summarizes their effects, and raises questions about present-day vulnerabilities to conventional air attacks. The Note is based mainly on the detailed reports of the United States Strategic Bombing Survey. 27 pp. Ref. (Author)

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I. INTRODUCTION

The purpose of this Note is to draw lessons from the World War II attacks against German inland transportation as an input to a current study of possible Warsaw Pact conventional air attacks against targets in NATO's rear areas. It is recognized that the German inland transportation system of the 1980s is different from that of the 1940s. Road transportation now plays a major role in both short- and long-long-haul traffic. The Bundesbahn is more highly electrified and automated than the Reichsbahn, and may therefore have new vulnerabilities. Pipelines now carry a large fraction of the POL traffic. Nonetheless, it is believed that useful insights can be learned from the experience of German railroads and waterways under attack in World War II. The main source of information concerning these attacks and their effects is the United States Strategic Bombing Survey (USSBS), especially Refs. 1 and 2 in the list of References given at the end of this note.

Before World War II, commercial highway transportation contributed little to the total movement of freight traffic in Germany, less than 3 percent in terms of ton-kilometers, and most of this was short-haul traffic (less than 50 km). Pipelines contributed very little to total POL movement, except in the immediate vicinity of refineries. Inland transportation relied mainly on railroads (about 75 percent of ton-kilometers moved) and on barges and other watercraft (about 20 percent) [Ref. 1, p. 6].

Until late in 1944, German inland transportation was not a high-priority target for Allied air attack. Earlier the Allies had mounted a major tactical interdiction campaign against the French rail system to delay German reinforcements moving toward the Allied beachheads in Normandy, and a somewhat similar campaign had been conducted even earlier against the rail system in German-occupied Italy. These campaigns were carried out mainly by medium bombers and fighter-bombers, the strategic air force (the heavy bombers) playing only a modest role. As the Allied forces moved eastward from Normandy to the Rhine, the medium bombers and fighter-bombers continued to attack the enemy transportation system in a fairly narrow zone, extending from 30 to occasionally as far as 100 miles forward of the Allied lines.

But before September 1944, attacks by the strategic air forces against the railroads and waterways inside Germany had been sporadic or incidental: transportation targets in Germany itself were attacked chiefly as alternates to other target systems or as targets of opportunity.* In September 1944, however, railroads and waterways in Germany were moved up to near the top of the priority list for strategic bombing, and finally, in March 1945 (when the war was nearly over) German transportation as a target system received a definite, coordinated, high-priority plan of attack. The attacks with heavy bombers in September and October 1944 were felt at once and showed up clearly in the operating statistics of the railroads and waterways.

Apparently there were no attacks against pipelines as such; at any rate, I have found no reference in the USSBS to pipelines as specific targets. This probably reflects the minor contribution they then made to POL distribution.

* The exception was the mine-laying campaign against traffic on the Danube; that campaign began in April 1944 as part of the attack against German POL.

II. ATTACKS AGAINST WATERWAYS AND WATERWAY TRAFFIC

THE WATERWAY SYSTEM

The principal waterways in Germany during World War II were five northward-flowing rivers (the Rhine, the Ems, the Weser, the Elbe, and the Oder) together with a number of interconnecting canals, notably the east-west Mittelland Canal, which connected the four last mentioned rivers, and the Dortmund-Ems Canal, which together with several tributary canals in the Ruhr industrial region connected the Rhine with the Ems River and the Mittelland Canal. All of the main waterways in the north and west of Germany were thus joined in a single system. The Danube, rising in Germany and flowing southeastward to the Black Sea, provided an important means of transportation in the Balkans and was used to bring Romanian oil to Germany. However, there was no canal connection between the Danube and the waterway network in the northwest.*

Including the smaller canals and the navigable tributaries of the main rivers, the German inland waterways had a total length of about 7800 miles. At the beginning of 1944 the freight-carrying fleet in the northwest network numbered some 19,000 vessels with an average capacity of 360 tons; of these vessels, over 4000 served the Rhine and its tributaries. These Rhine watercraft were generally larger than those elsewhere in the northwest, averaging about 620 tons capacity. Thus the Rhine system alone carried nearly 40 percent of the vessel capacity (tonnage) in the northwest, and contributed probably more than 40 percent of the traffic in terms of ton-kilometers moved.

On the Danube, there were some 1300 vessels with an average capacity of about 560 tons [Ref. 1, p. 8].

WATERCRAFT AS TARGETS: MODEST RESULTS IN THE NORTHWEST

In the northwest, German inland shipping was never a primary target, but vessels were excellent targets of opportunity, and they were often bombed and strafed. During the whole war, about 5500 watercraft were reported as damaged or sunk by air attack in the northwest waterways, but the damage and destruction data are aggregated and it is difficult to assess what this number means. Most of the damage to shipping seems

* A canal connecting the Danube with the Main-Rhine system is now under construction.

to have occurred as a by-product of air attacks (especially heavy bomber attacks) against inland port cities. For example, in the port areas of Duisburg-Ruhrort alone, a total of over 2400 vessels were damaged or destroyed.

The effect of these attacks on fleet capacity was apparently minor until 1944--a reduction of about 2 percent in 1942 and 4 percent in 1943. Damage, sinkings, and the indirect effects of attacks against vessels may have reduced effective fleet capacity in the northwest by as much as 15 or 20 percent in 1944--a rather modest result, but not trivial [Ref. 1, pp. 25, 39].

THE DANUBE CAMPAIGN:

AIR-DELIVERED RIVER MINES HIGHLY EFFECTIVE

A few mines were laid by Allied aircraft in the Rhine and the Dortmund-Ems Canal in the summer of 1944, but mining in the northwest waterways was abandoned almost as soon as started, for reasons that I have not been able to identify. In the Danube the situation was different. As part of the attack against German POL, Danube shipping came under systematic air attack, beginning in April 1944, with bombing, strafing, and minelaying. About 43 percent of the Danube fleet was damaged or destroyed from April through December, with half of the total (and probably more than half of the sinkings) due to mines. The effect of the mines on crew morale was "tremendous" according to the USSBS, with desertions, manpower shortages, and resulting delays. Fifty-two percent of the mine detonations resulted in total losses, often with crew casualties. *Within three weeks of the beginning of the mine-laying campaign in April 1944, the tonnage being moved on the Danube had dropped by 60 percent, and traffic continued to decline during the summer and autumn.* According to the USSBS, "the damage, disorganization, disruption, and delay to navigation resulting from the intensive mine-laying campaign . . . slowed traffic decisively." [Ref. 1, p. 27.] Although I have not been able to determine the mine tonnage dropped or the number of delivery sorties involved, the delivery effort was apparently not large: the whole mine-laying campaign appears

to have been carried out by a single RAF Bomb Group stationed in Southern Italy [Ref. 5, pp. 177, 281, 297], which probably fielded about 30 aircraft, and almost certainly no more than 45.

With today's more sophisticated shallow-water mines, it is conceivable that the Warsaw Pact might achieve a major disruption of traffic in Western Europe's inland ports and waterways with a very modest number of sorties, especially in the short term at the beginning of a conflict before countermeasures could be organized and brought into efficient operation. If mines are fuzed for self-destruction after some appropriate interval, their use need not inconvenience the user himself if he wishes to open the waterways later for his own traffic.

DESTRUCTION OF BRIDGES OVER CANALS AND RIVERS

Dropping a bridge not only cuts off road or rail traffic across a waterway, it is also an effective way of stopping water traffic. Many instances can be cited. The autobahn bridge over the Dortmund Canal just north of Dortmund was bombed on 12 August 1943. Parts of the bridge fell into the canal, stopping navigation for 18 days. The autobahn bridge over the Rhine-Herne Canal near Duisberg (one of the main links in the Ems-Dortmund-Rhine system serving the Ruhr) was bombed into the canal on 20 November 1944, stopping navigation for 17 days. Three days later near Gelsenkirchen another bridge over the same canal was bombed, stopping navigation for 9 days [Ref. 1, p. 18].

Probably the outstanding example of this effect on water traffic is provided by the destruction of the suspension bridge over the Rhine at Cologne. As a result of bombing and the accidental detonation of demolition charges, the entire structure collapsed into the river on 14 October 1944, completely blocking the navigable channel and stopping both northbound and southbound traffic. Although removal of the wreckage was given very high priority and a major clearance effort was begun almost immediately, the channel was still uncleared when American troops reached Cologne 5 months later. Because of unusually high water for the time of year, some vessels were able to transit Cologne during the last 2 weeks of November and the first 3 weeks of December 1944,

but the volume of traffic was much reduced. In November, Rhine traffic (both southbound and northbound) was only about 20 percent of normal; in December, the figures were 30 percent of normal southbound and 10 percent northbound. These figures understate the effect of the closure, however, because they include short-haul traffic that did not have to pass Cologne. In effect, the dropping of the Cologne bridge reduced long-haul traffic to a trickle on a waterway previously one of the most heavily used in the world, among other results cutting the flow of coal and POL to the south and ore and timber to the north.

To the extent that the Rhine is still used for the transport of POL, the dropping of a few bridges upstream from Duisburg should have an immediate effect on the southbound delivery of POL (including POL already en route), thus increasing the demand for deliveries by other modes and complicating POL allocation problems. Because the last 4 or 5 months of the year are normally months of low water on the Rhine, water traffic may then be particularly vulnerable to interdiction by bridge debris.

BREACHING CANAL WALLS

Although the German canal network in the Ruhr was well-developed, there were a few critical links or nodes which, if not operating, would isolate the northern river and canal system from the Ruhr and the Rhine. The most important of these was the Datteln High Pool, a 15-kilometer-long junction basin connecting five canals: (1) the Dortmund-Ems Canal leading north to the Ems and joining the Mittelland Canal (the main east-west waterway), (2) the Datteln-Hamm Canal to Hamm, (3) the Dortmund Canal to Dortmund, (4) the Rhine-Herne Canal to the Rhine at Duisburg, and (5) the Wesel-Datteln Canal to the Rhine at Wesel north of Duisburg. The Datteln Pool had the highest water level in the whole canal system, and the draining of the pool would not only prevent intercommunication among the five canals, it would also stop navigation in the Rhine-Herne and Dortmund-Ems Canals by cutting off the water needed for the operation of their locks.

Surprisingly, although the Datteln Pool was higher than the surrounding countryside, little effort appears to have been made by the Allied air forces to breach its embankments. The embankments were, however, breached by bombs spilling over from a raid against a benzine plant at Datteln. The escaping water cut a huge gap, and the pool was drained [Ref. 1, p. 21]. This happened in March 1945; it was the final blow needed to reduce the German waterway system to near-impotence. Thereafter only a modest amount of short-haul traffic was possible on the northern and western waterways.

Failure to target the Datteln Pool embankments is the more surprising, because canal embankments nearby were carefully targeted and attacked successfully and repeatedly earlier in the war. The principal targets in these attacks were the Dortmund-Ems Canal at Ladbergen, about 30 km north of Münster, where the river Glane passes under the canal, and the Mittelland Canal at Gravenhorst close to Ladbergen, where the river Aa passes under the canal. At both Ladbergen and Gravenhorst the canals were contained between earth embankments, and the water level was considerably higher than the surrounding country. Ladbergen was attacked first on 23 September 1944, the embankments were breached, the canal was drained, and all through traffic was stopped for four weeks. Gravenhorst was attacked first on 21 November 1944 with similar results, traffic being stopped for three weeks. Attacks on these targets every three or four weeks kept these two canals closed until the end of the war, except for very brief intervals. As at Datteln, the bomb damage to the embankments was greatly aggravated by the erosion caused by the water escaping from the canal [Ref. 1, p. 17].

The effect of these attacks is shown by the record of traffic passing through the Münster locks on the Dortmund-Ems Canal just south of the point at which the two canals merged to form a single waterway. In the five months ending February 1945, monthly northbound traffic varied from 2 percent to 29 percent of normal; monthly southbound traffic varied from 2 percent to 30 percent of normal; total throughput in this period was reduced by nearly 90 percent. When the Datteln Pool embankments were breached in March 1945, essentially all traffic ceased.

OBSERVATIONS AND CONCLUSIONS

The strategic air attacks delivered in 1944 against the German inland waterway system soon reduced long-haul waterborne traffic to a trickle and greatly curtailed even short-haul movements.

According to the USSBS, the damage, delay, and disruption caused by the Danube mine-laying campaign reduced deliveries and slowed traffic on that river decisively. In the northwest waterways, the air attacks involved a much greater sortie commitment and had even greater effectiveness.

In spite of intensive repair and salvage work and ingenious countermeasures, the effect of the Ladbergen-Gravenhorst raids and the destruction of the Cologne Bridge on inland waterway traffic in Germany was disastrous, and the breaching of the Datteln embankments ended water traffic in the Ruhr area [Ref. 1, p. 23].

On the other hand, the targets chosen for attack were not the best available. The USSBS concluded that

. . . . a small tonnage on a few carefully selected targets would stop all important north German canal traffic and through traffic upon the Rhine River for an indefinite period and . . . this could have been accomplished early in the war, thus diverting a tonnage which the railroads were not prepared to handle in full [Ref. 1, p. 4].

The targets identified as best by the USSBS were as follows [Ref. 1, pp. 4-5]:

- o The Datteln Lock. Damage would stop navigation through the Wesel-Datteln Canal, drain the Datteln Pool, and stop navigation in the Dortmund-Ems, Rhine-Herne, and Hamm Canals.
- o The Münster Locks. Damage would stop all waterway traffic from the Rhineland-Ruhr to the north and east for many months.
- o The Rothensee Ship Lift. Even light bombs, if properly placed, would stop traffic on the Mittelland Canal between the Weser and the Elbe for a year or more.
- o Any suspension bridge over the lower Rhine. Dropping the span should stop through navigation on the Rhine for a long period.

Note that none of these would be difficult targets for today's precision-guided munitions, especially laser-guided bombs. The Rhine bridges might be targeted in any case in connection with attacks against road and rail transport, and destruction of the Datteln and Münster Locks might require only a dozen or so PGM-delivering sorties. The German waterways (if basically unchanged since the 1940s), could therefore be considered as quite vulnerable to plausible types of air attack.

The question is, what effect would such attacks have on the course of a NATO-Pact conflict, especially an attempted Pact blitzkrieg? How would it affect deliveries of important supplies (especially POL?) in the first week or 10 days? Would it, for example, suddenly throw a heavy burden on alternative modes of transport? What plans have been made to cope with the denial of water transport? Have there been changes in the waterways that make the USSBS conclusions inapplicable today?

Questions should also be asked about the vulnerability of the inland waterways in East Germany and the other countries in Eastern Europe--and in the Soviet Union itself, where the road network is quite poor, the rail network is sparse, and there is heavy reliance on river and canal transportation.

III. ATTACKS AGAINST THE RAIL SYSTEM

THE RAIL SYSTEM

At the beginning of World War II, the rail system in Germany was highly developed and complex, with many alternative routes, a large number of marshalling yards, excess capacity of permanent way (both in lines and yards), first-class maintenance, and excess shop facilities. Much of this was the result of pre-war planning for possible wartime needs. An example of such planning was the retention of equipment for servicing and repairing steam locomotives in the electrified links of the network.

The government-owned rail system (the Reichsbahn) consisted of about 55,000 km of line in 1937, before its expansion during the war to nearly 80,000 km by the inclusion of railroads in Austria, Alsace-Lorraine, and Luxembourg. Nearly all the lines were standard gauge, and about three-fourths of the main lines had multiple tracks. In 1937 the Reichsbahn carried freight totalling about 98 billion ton-kilometers, with another 4 billion carried by several small, short-haul, privately owned "feeder" railways.

The only element of the rail system close to full utilization at the beginning of the war was rolling stock, but by 1942 rolling stock had been greatly augmented by new construction and by seizure of cars and locomotives from occupied countries. The following tabulation compares rolling stock quantities and utilization in June 1937 (pre-war) and June 1944 (just before the beginning of the intensive Allied air attacks on German transportation) [Ref. 1, pp. 74, 75].

	<u>June 1937</u>	<u>June 1944</u>
(a) Freight cars owned	593,000	987,000
(b) Locomotives owned	22,000	38,000
(c) Freight cars loaded during month	3,761,000	4,007,000
(d) Freight car turn-around time (average)	4.7 days	10.0 days
(e) Length of haul (average)	181 km	276 km
(f) Average freight car speed from loading to turn-around, (e) divided by (d)	38.5 km/day	27.6 km/day

The Reichsbahn functioned with high effectiveness through the first four years of the war, generally meeting the demands of military deployments, expansion and dispersion of war industry, and territorial extension. The Minister of Transport regarded it as a "crisis proof" system [Ref. 1, p. 2]. The decline in freight car speed shown in the tabulation does suggest, however, some decrease in the efficiency of Reichsbahn operation even before the heavy air attacks against German transportation got under way.

Maximum monthly car-loadings in the earlier years of the war occurred in the summer or autumn, with between 4.1 and 4.7 million cars loaded per month [Ref. 1, p. 75]; the 4.0 million in June 1944 was therefore close to the maximum achieved previously. Car loadings began to drop in September, 1944, slowly at first and then rapidly. A substantial excess of locomotives and cars consequently developed within Germany after the middle of 1944, as industrial production declined, the boundaries of the Reich contracted, and average haul-length grew shorter.

STRAFING ATTACKS AGAINST LOCOMOTIVES
AND ROLLING STOCK

Reichsbahn rolling stock and locomotives were attacked by strafing and by bombing. The bombing was largely a by-product or bonus of heavy bomber attacks against marshalling yards and industrial and city targets. Although there were occasional strafing attacks in earlier years, strafing began in earnest in 1943 by escort fighters returning from bomber raids. Later, in 1944, tactical fighter-bombers began to fly missions with train strafing as their primary objective. Locomotives were the preferred target. Strafing by returning escort fighters was limited to targets of opportunity, and the USSBS assessed the effects of such strafing as small [Ref. 1, p. 42], although these attacks probably helped to reduce day-time use of the rail lines. Tactical fighter-bomber strafing raids carried out as part of interdiction plans generally included larger numbers of sorties and were more concentrated, and were therefore more effective.

Between August 1944 and the end of the year, strafing claimed an average of about 20 locomotives a day, and the average rose to over 50 a day by February 1945 [Ref. 1, p. 50]. The heavy loss of locomotives and rolling stock would no doubt have been quite serious except for the surplus of rail equipment accumulating in Germany as the borders of the Reich collapsed inwards. Moreover, the damage done to locomotives by strafing (typically by 0.30 or 0.50 caliber guns) was often quickly repairable. The Reichsbahn repair facilities were excellent; special repair trains with complete welding equipment were fielded; and repairs were efficiently carried out right up to the last month or two of the war. Lack of power was not a factor in the breakdown of the German rail system [Ref. 1, p. 76].

The principal result of strafing seems to have been to reduce train movements during daylight hours and thus cause delays in freight deliveries and force redeployments. Other types of attacks against the rail system also caused major delays, however, and it is difficult to assess their relative contributions. It appears from the USSBS reports that strafing was one of the less important factors contributing to delay [Ref. 1, pp. 4, 50].

The USSBS reports say surprisingly little about cargo lost to strafing, although cars containing ammunition or flammable liquids were often completely destroyed when strafed [Ref. 1, p. 50]. I could find no reference to attacks specifically targeted against POL tank car trains. The rail LOCs serving the German forces during the Battle of the Bulge were subjected to particularly intense strafing attacks as soon as weather permitted, and daylight traffic was then largely suppressed. "Ten percent or more" of the German replacement tanks moving by rail to the fighting areas were destroyed en route [Ref. 1, p. 48], but it is not clear that all of this loss can be credited to strafing.

Strafing attacks also damaged signal wires and telephone installations along the right of way, and contributed to the degradation of rail system communications which had become serious by January 1945.

BOMBING ATTACKS AGAINST THE FIXED ELEMENTS OF THE RAIL SYSTEM

Marshalling yards* were the principal targets of the heavy bomber missions directed specifically against the rail system. The large yard areas matched the limited accuracy of the heavies, which bombed from high altitudes and often in poor visibility (the RAF's heavies bombed at night). Occasionally the heavies also went against bridges and viaducts; and all elements of the rail system suffered to some degree from heavy bomber attacks against industrial and city targets.

The medium bombers and fighter bombers allocated to rail attacks concentrated on bridges and rail lines in addition to the strafing attacks discussed earlier.

Of the Reichsbahn's 31 divisions, the 8 eastern divisions were seldom attacked by U.S. or British bombers, or, for that matter, by Soviet aircraft. The central divisions were attacked by the heavies (which had the necessary range), but relatively little by the mediums and fighter-bombers until the ranges from Allied bases shortened in the last few months of the war. The western divisions of the Reichsbahn were attacked the most heavily, by mediums and fighter-bombers as well as heavies, and over a longer period.

* Multiple-track yards for sorting out freight and other cars and assembling and disassembling complete trains.

Marshalling Yards

Germany was provided with an exceptionally dense network* of marshalling yards, much denser than in Italy, where Allied attacks on the yards had produced a marked reduction in both military and non-military throughput. There thus arose some disagreement among Allied planners as to the emphasis to be given to marshalling yards as targets in the campaign against German rail transportation. In general, the British tended to regard them more favorably than the Americans, but both air forces gave them a high priority. This was understandable in view of the limited accuracy of the heavies, but in retrospect it seems probable that a different allocation of the available sorties (with fewer attacking the yards) would have then been more productive.

As a way of stopping through traffic, a yard attack was seldom effective. At least one of the many through lines in the multiple-track yard network usually survived intact, and (because of the concentration of materials, equipment, and manpower at the yards) the most critical line repairs could usually be accomplished there in minimum time--typically a matter of 24 hours or less[†]--substantially less than the time required for track repairs elsewhere.

Because of the number and distribution of the German marshalling yards, and because each yard typically had an undamaged capacity that exceeded local needs, the classification work from a damaged yard could usually be shifted to one or more operational yards nearby. In this way through trains could be made up and sent through the most heavily damaged yards while they were still unable to do classification work. German military traffic (which had first priority on the Reichsbahn), and especially the trains used to move combat units, were thus relatively little affected by even the heaviest damage to individual yards. Only when a large number of yards in a region were simultaneously out of operation was there serious delay in making up or receiving trains [Ref. 1, p. 51].

* For example, the Essen division alone (in the heart of the Ruhr) was served by 23 large marshalling yards [Ref. 1, p. 50].

[†] But to bring most of a badly damaged yard back into operation (to, say, 80 percent of undamaged capacity), required several weeks [Ref. 1, p. 51].

There is no evidence that the bombing of marshalling yards directly caused any shortage of locomotives or cars in Germany [Ref 1., p. 53]. Nor does it appear that such attacks caused much injury or loss of life among rail workers; at the large marshalling yards, at any rate, personnel were provided with good air-raid shelters and generally had ample warning to take shelter before the bombs began to fall [Ref. 1, p. 42].*

As with strafing attacks against locomotives and rolling stock, the contribution of the heavy bomber attacks against the marshalling yards is difficult to assess in isolation. There are no data as to the number of trains that would have been dispatched in the absence of the marshalling yard attacks but were not dispatched because of the attacks. As to delays, most of them appear to have been due to line cuts outside the marshalling yards, but after September 1944 marshalling-yard damage certainly contributed to the delays in the movement of nonmilitary traffic. According to one apparently reliable German wartime official [Ref. 1, p. 54], 93 percent of the trains delayed were mixed trains requiring classification. According to the same source, the overall classification capacity of the Reichsbahn had been reduced by bombing to about 40 percent of rated capacity by the spring of 1945. This reduction inevitably had a highly adverse effect on German economic efficiency and the output of war industry. The concentrated marshalling-yard attacks in the Ruhr late in 1944 and early in 1945 severely curtailed the Reichsbahn's ability to handle traffic there, especially the (normally heavy) traffic originating and terminating locally. Early in 1945, when the Allied armies crossed into Germany, some of the cities in the border areas were evacuated by the Germans and their railyards totally destroyed. This added indirectly to the effectiveness of the air attacks against yards.

The overall assessment by the USSBS is that marshalling-yard attacks had only very limited "tactical" success in delaying or stopping priority traffic (which was mainly military), but that eventually these attacks did contribute significantly to the reduction of "economic" traffic [Ref. 1, p. 4] in Germany.

*The situation could be very different in a Warsaw Pact attack in the mid-1980s: shelters may be lacking and warning times extremely brief.

Railway Signals, Telecommunications
and Electric Power

Apart from the damage done in some strafing attacks, which targeted them directly, the railway signal and telecommunications systems appear to have suffered only collateral damage--the result of attacks directed primarily at targets such as bridges, small stations, and marshalling yards. This is understandable, because the "command and control" elements of the rail system were quite small in comparison with both the other fixed features of the rail system, and with bomber accuracies. Nonetheless, the collateral effects on these systems were substantial. They were comparatively "soft," and, when they suffered major damage, repairs were time-consuming, requiring special skills [Ref. 1, p. 52]. A switch-signal interlocking installation (at least one being located at each station) took 3 to 10 days to replace.

Telecommunications (telephone and teletype) were highly centralized, with Berlin at the hub. Overhead pole lines were particularly vulnerable, and by February 1945 even the (buried?) cable circuits had become unreliable, with connections to Berlin out sometimes for as long as 3 to 5 days. By March 1945 the telecommunication system was operating only in segments, with almost no direct contact with Berlin. In the closing days of the war, the Reichsbahn was attempting to keep account of train locations and movements by means of motorcycle dispatch riders [Ref. 1, p. 78].

The USSBS conclusion is that "The inability of the railroad communication system to withstand the attack of modern warfare greatly increased the difficulties of operation and contributed directly to the general breakdown of the transportation system" [Ref. 1, p. 78]. The present high degree of centralization and automation of Bundesbahn operations, including remote blocking and switching, and the possible "softness" of Bundesbahn telecommunications and control centers to attacks by precision-guided munitions, suggest that the vulnerability of the Bundesbahn's "command and control" system should receive careful attention.

Attacks specifically directed against the electrified links of the Reichsbahn are scarcely mentioned by the USSBS, although it does hint that these links were regarded as especially vulnerable [Ref. 1, p. 14]. Only a small part of the Reichsbahn was electrified in the 1940s, most of it in Southern Bavaria, where attacks of all types against the rail system were relatively light. Power for the electric locomotives was occasionally disrupted, for example, by a raid on the Munich main railway station [Ref. 1, p. 57], but the World War II evidence from Germany is too sparse to provide clear evidence of the special vulnerability of the electrified segments of the Reichsbahn.

Rail Lines

Attacks against rail lines included attacks against tracks and roadbeds (outside of marshalling yards) as well as bridges, underpasses, viaducts, tunnels and small stations. Such line-cutting attacks were also referred to as "interdiction attacks," to be distinguished from the strategic bomber attacks against German industry, POL, transportation, etc. This distinction was based on differences in organizations and weapon systems: the line-cutting attacks were carried out mainly by the "tactical" air forces using fighter-bombers and medium bombers. Compared with the heavy "strategic" bombers, these aircraft usually operated nearer to base, carried smaller bomb loads, attacked at lower altitudes, acquired targets visually, and achieved greater delivery accuracy. They were, therefore, more suitable for attacks against railway "point" targets, whereas the longer-legged, less-accurate heavies were more suitable for attacks against the larger rail targets such as marshalling yards. By the end of 1944, when the Allies had the use of forward air bases in France, the tactical air forces were able to undertake bombing and strafing missions inside Germany, and the distinction between "interdiction" and "transportation" attacks became more and more artificial. For example, both the mediums and the heavies targeted rail bridges in the Ruhr isolation campaign that began at the end of January 1945.

Attacks against rail lines inside Germany (apart from marshalling-yard and station attacks) began in 1943, but were only sporadic until the summer of 1944. Unfortunately, because the data available from

the Reichsbahn were quite aggregated, the USSBS teams were unable to quantify the contribution of the various attacks by target type, much less to identify the specific cause of each of the line cuts reported [Ref. 1, p. 63].

As defined in the Reichsbahn records, a "line cut" was counted each day when a line had been unusable for the previous 24 hours. Target for target, those that took longest to repair (typically bridges) would therefore contribute most over time to the daily record of line cuts, but the USSBS data don't enable us to judge which target type (or set of target types) should have been chosen to maximize attack efficiency in terms of measures related to both inputs and outputs, e.g., line-cut-days achieved per sortie. By such a measure, attacks against tracks in rail links in open country may have been most efficient because of their relatively low sortie requirements or low aircraft loss rates or both. On the other hand, a mere enumeration of line cuts is not a good measure of reduction in network throughput capacity. Bridges (at any rate major bridges) are often constrictions or choke points in a rail or road network, and a line cut there may have exceptionally important payoffs. And in weather (like that in Europe) in which visual target acquisition and bomb damage assessment are intermittent, there are obvious advantages to attacks that take out targets with long reconstitution times.

By October 1944 the Reichsbahn was reporting a substantial number of cut lines each day. During the month, the numbers ranged from 48 to 109 for multiple-track lines with all tracks cut, and from 4 to 22 for single-track lines. With considerable daily variations the numbers continued about the same through January 1945, and then in February increased steeply, by the end of the month touching 200 for multiple-track lines with all tracks cut [Ref. 1, pp. 63, 74].

A rough measure of the effect of these line cuts on Reichsbahn traffic is given by the average daily number of trains "delayed," that is, scheduled but not dispatched within 6 hours.* In June 1943, a

* There appears to be no record of the number of trains not scheduled at all, or whose scheduling was postponed, as a result of attacks against rail targets. ("Scheduled" appears to imply that the train was assembled and more or less ready to go; in other words, it was not being held up by marshalling-yard delays. But this interpretation is not entirely certain.)

month when the Reichsbahn reported only one line-cutting attack, the daily average of delayed trains was only 53 out of many thousands of trains scheduled. In June 1944 the total had reached 275, in October it exceeded 1000, and December it had reached nearly 1700 out of a declining number of trains scheduled [Ref. 1, p. 63]. Presumably the fraction of scheduled trains that suffered delay continued to rise during the last months of the war, but data are not available. By the end of March 1945, complementary marshalling-yard and line-cutting attacks had effectively isolated the Ruhr from rail access [Ref. 1, p. 15].

PREPARATIONS FOR REPAIR; REPAIR TIMES

The Reichsbahn carried out repairs vigorously and efficiently, having learned the job during a long period of "apprenticeship" when Allied attacks were relatively light. Reichsbahn staff were often supplemented by labor from the Todt organization, from nearby industry, and even from the German army. In general, there was no shortage of personnel for repairs. The Münster division (one of the 23 western and central Reichsbahn divisions that came under substantial Allied air attack) provides an example of the preparations made. This division alone maintained 10 tracklaying trains with 40 to 70 men each, 5 switch-tower repair trains, 5 communications repair trains, and trains specially fitted for water-station repair, bridge construction, and locomotive welding. Extra turnouts were maintained at all junction points and larger stations, and extra cross-overs at main terminals. Restoration was therefore rapid, although materials for repairs were sometimes in short supply, and there appears to have been some shortage of heavy earthmoving equipment [Ref. 1, pp. 51, 63-68].

The following tabulation summarizes Reichsbahn repair times for representative line cuts. It should be remembered that there was great variation depending on individual circumstances; some of the bridges remained out of use for months. In the last two or three months of the war, repair times increased as repair capabilities were overwhelmed.

<u>Target Damaged</u>	<u>Repair Times</u>
Track section	1 to 3 days (sometimes less near stations)
Underpass or tunnel	3 to 10 days
Major bridge or viaduct (span dropped)	10 to 20 days (sometimes much longer)

Would repairs take as long today? Span lengths in some of the new bridges are longer, and dropped spans are therefore more difficult to replace. The complexity of repairs everywhere has probably increased as a result of further electrification and greater centralization and automation. Highly skilled manpower would therefore be required, and enough might not be available to handle multiple repairs simultaneously. Moreover, experience in responding quickly to damage caused by enemy attack is lacking. Replacement parts and equipment (although adequate for peacetime) may be insufficient for wartime demands or, even if sufficient, not positioned so as to be quickly available at the points of need. On the other hand, heavy earthmoving equipment is probably in better supply than in the 1940s, at least in the civilian economy (from which it might take some time to extract it). On balance, it seems plausible that line-cut repairs would take somewhat longer in the 1980s than in the 1940s, especially if a conflict in the 1980s began with little warning. Even simple track cuts, if they prevented traffic on a line for a couple of days, might achieve much in support of a blitzkrieg strategy.

ACCURACY OF ALLIED BOMB DAMAGE ASSESSMENT

Interestingly, the line-cut bomb damage assessments of the Allied air forces seem to have been quite inaccurate, greatly *underestimating* the amount of damage actually done. The marshalling yard BDA, on the other hand, was relatively good. The USSBS concluded that the air force BDA maps were "of no value" for assessing the number and location of line cuts achieved by air attack [Ref. 1, p. 63]. If the success of air attacks in cutting lines had been better understood, a greater part of the Allied air effort might have been allocated to such attacks.

EFFECTS OF RAIL ATTACKS ON MILITARY MOVEMENTS

For most of the war, the Allied air attacks against the Reichsbahn were designed as deep rear-area attacks with long-term or "strategic" objectives in mind: to reduce the output of German war industry and to make it difficult for the German armed forces (the Wehrmacht) to redeploy large units rapidly over long distances between theaters. Tactical considerations were often dominant in the short run, however, especially during the Battle of the Bulge (late December 1944 and early January 1945) and the subsequent interdiction attacks aimed at rail transport in the immediate rear of the German armies as the Allies approached and crossed the Rhine.

During the Battle of the Bulge, the Allied air forces conducted an intensive bombing of rail-line targets and marshalling yards and strafed trains and road traffic in an area extending from the U.S. lines back to Cologne, Coblenz, and Trier. This concentrated, local campaign, using heavy bombers as well as tactical aircraft, was designed to have and did have an immediate effect on German movements close to the battle area. Replacements and supplies moving by rail were slowed significantly and suffered attrition en route, having to take circuitous routes and to move mainly at night or in bad weather. Railheads were pushed farther back into the German rear, lengthening the journey for supply trucks which, together with their fuel, were already in short supply. Much of the German logistic traffic failed to reach its destination in time and was, in effect, stopped [Ref. 2, pp. 53-58]. This story is well known. What is not so well known is that, before the Germans began the Ardennes offensive, the initial assembly of the Panzer divisions in preparation for the battle was delayed by about 2 weeks because of the slowness of the German rail transportation on which it relied [Ref. 1, p. 48].

Until the heavy air attacks against German transportation began in September 1944, the Reichsbahn was able to give good service to the Wehrmacht. When individual marshalling yards were damaged, the use of completely made-up trains allowed military traffic to move with only small delays. The Wehrmacht had absolute priority over other traffic,

and the degradation of rail service due to air attack was for a long time shifted successfully to the nonmilitary users of rail transportation. Having the benefit of a well-understood set of priorities, years of practice in their application, and the authority to enforce them, the Reichsbahn was able to meet most of the Wehrmacht's demands during the first month of heavy attack. Even in November and December 1944, train movements of army divisions* sometimes achieved 150 miles or more a day [Ref. 1, p. 47], although they could not be relied on except in the relatively unharmed eastern region of the Reichsbahn.

By the end of October, however, after a month's heavy air attack, the Reichsbahn's ability to meet the Wehrmacht's demands was definitely impaired in terms of both strategic redeployments across Germany and tactical redeployments in the West. General Thomale, Inspector General of Panzers, stated after the war that early in 1944 a Panzer division could have been moved from the Eastern Front to the West in 10 days, but that by October the same movement would require 20 to 30 days, because of the inability of the western lines to receive trains at the tempo with which the eastern lines could dispatch them [Ref. 1, pp. 47-48]. A movement from West to East would have presented even greater problems because of difficulties in the West in making up trains and dispatching them in rapid, orderly succession so as to maintain large-unit integrity.

In assessing the effects of air attacks against the German rail system, the only effect on military movement that can be quantified, even approximately, is delay. Sometimes delay was sufficiently great so that movements were cancelled en route or before starting, but data on cancelled ("stopped") movements were not collected by the USSBS teams, no doubt because they were not retrievable from the Reichsbahn records. Information on stopped movements is largely anecdotal.

In the nature of things, movements contemplated but not ordered are seldom recorded, even in unit histories. But the USSBS plausibly remarks that the growing unreliability of rail travel must have

* Movement of a Panzer division required 50 to 80 trains of 30 to 60 rail cars per train--a considerable demand on rolling stock and rail line capacity.

influenced the decisions of commanders and made them less willing to undertake movements by rail [Ref. 1, p. 48], thus reducing mobility or throwing a further burden on the Wehrmacht's declining resources for movement by road. When delays are frequent and unpredictable, mutually supporting multi-unit military movements are difficult to plan and may not even be attempted. When the movements required by the evolving military situation are not ordered, or, if ordered, are not carried out as planned, the result is a decline in the efficiency with which military assets are used. Delays, frequent and unpredictable, produce disruption and lead to defeat. This was the sequence of events from November 1944 to May 1945.

OBSERVATIONS AND CONCLUSIONS

Although Western Germany and the Benelux nations have an exceptionally fine network of modern multi-lane highways and secondary roads, rail transport remains vital to NATO's rear-area logistic support. As one observer has put it, "logistic support during mobilization means host-nation transport, and host-nation transport means rail transport."

It is arguable that Western European rail transport is now considerably more vulnerable than it was in 1944, because of

- o The multi-national division of operating responsibility.
- o The longer spans of some of the new bridges.
- o The greater technological sophistication of the system (automation, remote control, electrification).
- o The greater dependence of repairs on highly specialized (hence scarce) labor.
- o The lack of practice in (and preparation for ?) handling repairs in many places simultaneously under combat conditions.
- o In a Warsaw Pact blitzkrieg attack, little time to learn and adapt--no benefit of "gradualism."
- o The greatly increased accuracy of air-to-ground weapons (e.g., laser-guided bombs and other precision-guided munitions).

This is not the place to develop a detailed attack plan against NATO rail transport, but it is interesting to review the conclusions of the USSBS with the changed conditions in mind. The USSBS ranked the types of rail targets in the Reichsbahn in the following order of preference for attack [Ref. 1, p. 4]:

1. Line cuts, preferably bridges, underpasses, and viaducts, when carried out systematically.
2. Track sections in throats of yards.
3. Rail telecommunications and signals.
4. Servicing facilities at local terminals (fueling, etc.).
5. Rolling stock.

Marshalling yards (except for the throats of yards) were not on the list and were apparently assigned even lower priority. According to the USSBS, "line cutting is . . . the only effective method of reducing the movements of troops and supplies in complete trains." Fighter-bomber attacks against small stations, main trackage outside stations, and bridges permitted "a much more complete paralysis of enemy rail transportation than the activities of heavy bombers against yards" [Ref. 1, p. 4]. In short, the USSBS found the greatest payoff in the destruction of systematically selected point targets visually acquired by fighter-bombers and medium bombers, rather than in massive raids against large-area targets.

This conclusion would probably be reinforced by today's conditions. Line cuts would still have priority, and not only because they are now so easy to achieve. Cuts of even a few days' duration could have serious consequences in the face of a blitzkrieg attack launched with little warning. Because of extensive electrification and automation, the command-and-control and power systems may have moved up into second place on the priority list. Their vulnerabilities clearly deserve careful study.

Although NATO rear-area vulnerabilities are the focus of this Note and the broader study which it supports, these observations on rail system attacks should not be regarded as relevant only to Western Europe. They may be useful in examining rail vulnerabilities elsewhere, in Eastern Europe, for example, and in the southern and eastern regions of the Soviet Union, where the roads are generally poor, the rail network very sparse, and Soviet military operations might depend critically on uninterrupted rail transport.

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