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OFFICE OF STRATEGIC SERVICES
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RAILWAY TRANSPORT
AS A
STRATEGIC TARGET IN JAPAN

An analysis of transport targets
based primarily on experience in Europe

28 September 1944

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The operating characteristics of Japanese railroads make them a somewhat higher priority strategic target than were the lines in occupied Europe. However, land transport should still be rated fairly low compared with key industrial targets.

As among the various types of rail targets, bridges, cuts and open lines appear to be most desirable. Locomotives are relatively costly in terms of air effort and relatively ineffective in terms of results upon enemy economic potential. Yards should be ranked low and are definitely less desirable than bridges as a means of blocking traffic in specific areas. The characteristics of Japanese tunnels make them a somewhat more desirable target than they were in Europe.

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RAILWAY TRANSPORT AS A STRATEGIC TARGET IN JAPAN

I. SUMMARY AND CONCLUSIONS

Although rail transportation is extremely important to Japan's war effort, it should not be rated as a top priority target system for strategic bombing. On the other hand, the operating characteristics of Japanese railroads make them a more desirable target than the German lines. This analysis is purely in terms of strategic attack and is not concerned with transport as a tactical target designed to hamper military operations in a combat area.

The principal advantages of attack on rail targets in Japan arise from (1) the present tightness in operation, (2) the comparatively small number of important lines and alternate routes, (3) the relative lack of other types of transport, (4) the frequency of bridges, tunnels, and cuts in areas where slides may occur, and (5) the basic weaknesses resulting from single track, narrow gauge, slow speed operations.

The disadvantages include (1) the general flexibility of rail operation, (2) rapid recuperability and hence the need for frequent repeat attacks, (3) the "depth" of transportation in the economy, (4) the relatively small amount of direct military traffic, and (5) the opportunity open to the enemy of selecting the areas of the economy to be affected by overall reductions in capacity.

As to types of rail targets, bridges, cuts and open lines appear to be most desirable in terms of air effort per unit of damage. Locomotives are relatively expensive and ineffective targets, although much better than freight cars. Yards require a comparatively great effort and should be ranked below bridges with respect to blockage of specific areas. Tunnels in general are difficult to damage, although Japanese terrain definitely makes them more important than they were in Europe. Area isolation, although a fairly effective technique, would be very costly. Other types of targets are of minor importance.

It must be emphasized that this analysis does not take into account the number of plane types available for attack on Japan. Thus if fighters are available, locomotives may be attacked without requiring diversion of effort from other targets. Other operational factors might require revision in the relative priority assigned herein.

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II. GENERAL CONSIDERATIONS

A. In Favor of Rail Targets

The railroad system of any developed country is vital to its industrial and military strength. Movement of the huge tonnages of raw materials required by industrial activity is virtually impossible without an efficient and wide-spread network of railroads. This is particularly true of Japan, where motor transport is relatively undeveloped, where river traffic is practically non-existent, and where the availability of coastwise shipping is limited by heavy import and military supply demands.

In connection with shipping, it should be noted that future prospects of diverting traffic from the rails are not very great. As U.S. forces advance in the Pacific, Japanese supply lines will tend to be shortened, but it is not clear that a net saving in vessel requirements will result. Offsets include probable increases in imports of substitute materials from North China and Manchuria (e.g. lower grade bauxite) and increased movement of supplies and equipment in support of land operations. Furthermore, shipping losses may be expected to increase; even if only the present rate is maintained, it is doubtful whether any cushion will remain to permit return of appreciable tonnage capacity to the coastwise trade.

A general attack on rail transport in effect becomes an attack on all industry. Neither military nor civilian production can continue without the mass transportation facilities provided by the railroads of Japan.

Even if attack on land transport results only in a slowing down of operations, such attack may still have some strategic value. Increased time in transit for materials and products ultimately means either that a greater proportion of goods is in freight cars and that less is available on the fighting front, or else it means that more materials must be provided to maintain a given level of output plus minimum working inventories. Furthermore, any reduction in train speeds on single track lines has a direct effect on the number of trains which can be operated.

With the increasing tempo of war production in the past few years plus the diversion of traffic from water to rail as a result of the shipping situation, the Japanese railroad position today is extremely tight. Total freight traffic has increased from 121 million metric tons in 1937 to an estimated 183 million tons in 1944. This 50% increase has been accompanied by stringent government regulations. Passenger fares have been increased and service has been cut drastically to free the lines for the movement of freight; and permits are required for long passenger trips. Passenger cars released by schedule changes were to be converted to freight cars. Average freight loads per car have been substantially increased. Loading and unloading at night and on holidays have been required. The number of mixed passenger-freight trains has been increased as a method of improving locomotive utilization, although probably at the expense of slower passenger service. A priority system for the movement of freight has been instituted; Japanese broadcasts have indicated a reduction of 4% in the movement of "non-priority" goods between 1942 and 1943. Strenuous efforts are made to fill the seasonal trough during summer months.

All these measures point to extreme tightness. However, to maintain perspective, we should observe that Germany instituted sharp reductions in passenger train schedules and a progressively tighter priority system for freight very early in the war, even before being subjected to heavy air attack on rail facilities. (Permits were not required for passenger travel in Germany until July 1944, primarily because of the administrative difficulties involved.) Strategic air attacks on railroads have not had a decisive effect on Germany's military potential. On the other hand, Germany's "cushion" of adjacent subject countries (whose transport facilities could be reduced to prevent collapse of the Reich) is not available to Japan.

There are only a few principal lines in Japan. By far the most important are the Tokaido and San-yo Lines, which together form a through line connecting Tokyo and Shimonoseki; this route handles substantially more traffic than any substitute routes and if rendered inoperative would create considerable difficulties in the production and distribution of important war materials, especially coal and steel. Although the most important traffic would be shifted to alternate lines, the limited capacity of these lines would not permit complete diversion.

The rugged terrain in Japan has forced the construction of an estimated 1200 tunnels and 44,000 bridges along the 30,000-odd kilometers (approximately 20,000 miles) of railway line. The high frequency of such targets makes it difficult to pick out particular structures along a given line but, on the other hand, the need for exact spotting is correspondingly reduced.

Most of the lines in Japan are single track and have low tonnage capacities, not only as a result of grades and curves, but also - and more fundamentally - because of the narrow gauge construction. Within these limitations, however, the Japanese operate very efficiently, running substantially more trains per day over important single track lines than U.S. railroads. In addition to frequent sidings and automatic signalling, extremely close scheduling of train movements is essential. Interruptions, sudden changes in operating requirements, unaccustomed classifications in yards with little slack available, and other conditions arising from air attack would cause considerable reduction in the number of trains run. A sudden influx of new traffic diverted from a bombed line would call for virtually complete revision of schedules, as well as changes in the directional balance of equipment. With limited capacity on alternate routes, these disruptions would, if continued, have serious effects on military and indirect military output.

B. Against Rail Targets.

Railway systems are made up of a network of lines, each handling a very small part of the total traffic. As a result, the system has great flexibility. Generally, there are a number of alternate routes between any two points. Even though these alternates tend to be more circuitous and of lower capacity, they can, nevertheless, be used to move the most urgently needed items around a break in the direct line. With a network of lines, comparatively little direct damage to war production results from the cutting of any one line.

This point becomes more significant if we consider the importance of rail transport to military strength from a "use" standpoint. It is estimated that only about 15% of the traffic on Japanese railways is for direct military use; this includes materials and fuel going direct to Army and Navy installations as well as the tanks, guns, engines and other finished products. Indirect military tonnage (including the materials and fuel going to plants producing war goods) accounts for an additional 50%. The remaining 35% constitutes the civilian base.

It is clear from the above that only a small part of the traffic moving over the average line will have a direct relationship to military strength. Moreover, diversion possibilities may be such as to cause no material delay to such traffic. Usually, a substantial portion of the military traffic can suffer temporary delay in transit without impairing front line strength.

The indirect effects could be significant. But before this, the cushion of civilian traffic would have to be reduced to a minimum. Just how much slack there is in the Japanese civilian economy cannot be determined. Although the Japanese entered the war with a low standard of living and have had reductions in this standard since then, it must be assumed that further belt-tightening is possible. Certainly, experience in Europe shows what great elasticity exists. Moreover, beyond the civilian economy, there are possibilities of conservation in the flow of material for indirect military uses. For example, ways will be found to reduce the consumption and movement of coal, which represents close to 50% of the tonnage originated. Lumber, which accounts for 10% of the total, can also be conserved when necessary. For a large range of materials, industry can find ways and means for doing without or with less, at comparatively slight cost to war production.

Because of the geographic spread and the flexibility of the rail network, isolated or limited attacks would result in little more than annoyance to the enemy. Since most of the railroad targets have great recuperability, constant policing is necessary to prevent transport capacity from being restored. This calls for a scale of effort far in excess of anything likely to be available against Japan for at least six months. This problem will be covered more fully hereinafter.

It is believed that Japanese rail capacity is limited now primarily by the inability of important lines to handle more trains per day. Second in importance is the inadequacy of car supply. Locomotives apparently do not constitute a bottleneck. With respect to line capacity, frequency of sidings and signalling are the determining factors; on single track lines, speed is extremely important. Sidings are already quite close together; many single track sections have a maximum of 4 or 5 kilometers between sidings. The next step is double-tracking, but difficulties of terrain and the general tightness in manpower and materials preclude any major changes in track. Signalling is undoubtedly being improved but the increased train capacity possible by this method is limited by the more fundamental consideration -- sidings. The Japanese solution then must be to run longer trains with cars fully loaded; although speed is sacrificed, more tonnage may be handled per line.

The weight of trains is limited by the tractive effort of the locomotives available. The average steam freight locomotive in Japan has a tractive effort of about 32,000 pounds -- compared with about 58,000 pounds in the United States. As a result of this, plus grades and curves, the average train in Japan before the war had a gross weight of between 600 and 650 metric tons, including 34 cars carrying an average of 6 to 7 tons. At the present time, train weights are estimated at 770 metric tons, including about 35 cars carrying 10 tons. Thus, revenue load per train has increased from little more than 200 tons to about 350 tons. It is doubtful whether the older locomotives can exceed this level. One solution, however, would be the construction of more efficient motive power.

Here, too, there is a maximum practical limit. Narrow gauge lines create a basic engineering limitation. The light rail used in Japan is another. Nevertheless, it is to be assumed that new locomotive production is designed to permit substantial increases in train weight. Significant effects on total transport capacity must await the passage of time; thus, with a stock of 6,000 locomotives, production of about 600 locomotives per year (a liberal estimate), export of 300, and retirement of 100, and assuming the tractive effort of new locomotives averages 40,000 pounds, then the average tractive effort of all locomotives in service would increase only a few hundred pounds per year. This does not yield a significant change in load capacity.

On the other hand, the flexibility of motive power makes it possible to reduce train speeds and haul heavier loads. It may well be that our estimate of current average train weight (770 metric tons) has been exceeded and that the remaining slack is quite small. Although the extent of this is not determinate, it is clear that some flexibility exists. Thus, it may be possible to move substantially more tonnage over lines which have reached the limit of their daily train capacity. However, on single track lines, reduced speed means a reduction in the number of trains run, and hence total tonnage moved does not increase at the same rate as average tonnage per train.

Another source of flexibility is the possibility of further reductions in passenger service, thus freeing the lines for more freight trains. This too is indeterminate. Each additional cut impinges further on essential travel. Most of the obvious slack has been taken up but selective reductions may still be possible. This problem must be handled by analysis of individual train operations, consideration being given to timing and purpose of travel, alternate means of transportation, possible reductions in frequency of service coupled with increased train lengths and/or more crowding of cars, etc. The only safe assumption is that further cuts can be made when necessary.

The following excerpts from a report of the Director General of the French National Railways to the Secretary of State for Transportation, dated 1 June 1944, indicate the nature of the rail operating problem in an area subject to bombardment, strafing, sabotage, and requisition by Germany. "Our stocks (of rail) disappeared and it was necessary to cease operations on certain lines...During the month of May, the S.N.C.F. recorded 296 employees killed, 511 wounded, and 287 passengers killed, 245 wounded in trains which were bombed...Suspension of traffic and the tying up of trains considerably diminished the shipment of material for use of the S.N.C.F...The average operation per locomotive decreased from 81 km. per day per locomotive in service in November 1942 to 65 km. in March 1944 and to 50 km. on the first of June and it continues to decline rapidly...We have attempted to increase the delivery of material and have instituted a system of priorities but even that has been insufficient and it has been necessary to suspend much traffic...We hope to hold out in spite of everything."

Although subject to large and frequent attacks by Allied aircraft from nearby bases, although materials and equipment were requisitioned (or denied) by Germany, although protection against sabotage involved precautions which slowed down operations, nevertheless the French railroads have continued to function and to "hope to hold out in spite of everything." This experience suggests that land transport is not a high-priority strategic target, especially in the case of Japan, where the air force available for attack will be relatively small, where frequency of attack is much more limited by weather and other operational difficulties, and where the prospects of internal sabotage are very slim.

III. DETAILED CONSIDERATIONS

A. Line.

Track is obviously a vital part of a railroad system; if the track is cut, the number of locomotives and cars available loses significance. However, repair of bomb damage consists of removing and replacing damaged rail and ties and filling in the bomb craters. Only limited sections can be destroyed in one attack. Rail and ties are readily replaceable, standardized items, usually stocked at major terminals. If a series of attacks were made, the Japanese would store them at key points along the right of way, ready for immediate movement.

An engineer on a large U.S. railroad states that, even with 1800 craters 16 feet wide on a 100-mile stretch of double track, he could restore one track in 18-24 hours and have double track operation at 75% of normal capacity in about 36 hours. The technique consists of restoring one track by using undamaged sections of rails and ties on adjacent track; with one track functioning, work trains could lay spare rails and ties on the other track. Points and switches would be ignored to permit through running as soon as possible; these would be restored later. On single track lines, a work train can be driven in from both ends. In this case, repair time would be about 48 hours.

A study of bombing accuracy of MATAF fighter-bombers on rail lines indicates the following:

NUMBER OF DAMAGING HITS PER 100 BOMBS DROPPED

	Single Track		Double Track	
	20' Crater	30' Crater	20' Crater	30' Crater
Single Bomb Dropped				
At least one track cut	6.3	8.3	9.4	11.4
Two tracks cut	-	-	3.1	5.2
Two Bombs Dropped Together				
At least one track cut	6.3	7.3	7.8	8.9
Two tracks cut	-	-	4.7	5.7

These figures assume (a) line impassable if crater overlaps rail or ties, (b) widths of single and double track are 10' and 25' respectively, and (c) two bombs dropped simultaneously have an average separation of 30'.

If we assume an average of about 5 hits per 100 bombs dropped to cut a double track line, and 20 200-pound bombs per attacking plane, it would take one sortie to cut the double-track Tokyo-Shimonoseki line at any one point. Air operations over Japan, however, will probably not permit the relatively low level attacks characteristic of the MATAF tactics and, consequently, the accuracy ratio would have to be revised downward. Furthermore, to keep a line out for one day, a number of well-spaced hits would be needed. Allowing roughly for these considerations, as well as for the use of some smaller bombs (increasing the number of bombs per sortie), possibly 10 to 15 sorties per day would be required to keep this line out of service. Obviously the rate of repair in Japan is the governing factor and the above figure is taken as an approximation only.

The advantage of attacking lines is that they are less likely to be defended by planes or anti-aircraft installations. The disadvantage of cutting one section, apart from recuperability, is that truck substitution is a relatively easy means of by-passing the cut for short distances. However, this involves considerable delay to both goods and equipment. It is more effective to maintain two or three rings of cuts, spaced so as to make truck substitution more difficult, but this requires two or three times as many planes.

Lines skirting the side of a mountain may afford better targets, depending on the possibility of creating landslides. The target area is large and generally has few or no defenses. Some traffic interruption is likely to result even if only a small quantity of rock and debris falls. Even though bombing may not start an immediate slide, it may create conditions on which natural causes could operate later; thus, bomb blasts may open fissures which would be aggravated by rainfall and result in recurrent slides.

Japan has many sections of this type. Official reports refer to "repairs of the slopes of the cutting on the Iyokaminada-Simonada section"; reinforcement of retaining walls, restoration of the collapse in the slope of a cutting, etc. Many sections suffer from "incompetent" rock formations which make them peculiarly susceptible to slides. In some areas, hillsides are sprayed with a form of cement to form a water-proof crust. Where a line follows such terrain, it is possible to keep it out of use for considerable periods; if the hillside is unstable, continual slides will occur when the original debris is removed, until such time as the hillside can be stabilized. This makes a very inexpensive target.

Embankments in general are less desirable targets, although more desirable than open stretches of track. If filling operations do not prove sufficiently rapid, temporary trestles can be quickly thrown up. One source states that successful attacks on embankments with soft soil in Italy produce delays of 4 or 5 days.

B. Bridges.

Although bridges are important links in a railway system, they are difficult targets. A study by MATAF shows the accuracy achieved by P-47's on two types of bridges:

HITS PER 100 BOMBS

(All Bombs Dropped Singly)

	Bridge 200' x 30'		Bridge 400' x 40'	
	20' Crater	30' Crater	20' Crater	30' Crater
Direct Hits	1.14	1.14	3.04	3.04
Near Misses	.76	1.14	1.52	2.28
Hits on Approaches	4.5	6.0	3.3	4.0
Total Effective Hits	6.4	8.3	7.9	9.3
Sorties per Effective Hit (2 bombs / a/c)	7.8	6.0	6.3	5.4

If bombs are dropped in pairs, each aircraft has asmaller chance of hits, but if hits are made, there is more chance of two hits simultaneously. The average number of hits expected is the same. The decision is a tactical one, depending on whether fewer cuts with greater damage or more cuts with less damage are desired.

Tactics have a marked effect on the results of bridge attacks, and it is difficult, therefore, to apply conclusions from one theatre to another. Nevertheless some generalizations appear possible. A study of operations in Burma, covering 943 sorties against 8 bridges, indicates that 61 "hits which were seriously damaging to the bridge proper" were obtained out of 2,718 bombs dropped -- an accuracy rate of 2.24%, compared with 1.14% on small bridges and 3.04% on large bridges in the MATAF study. These figures do not include a number of hits on approaches, which would raise the percentage substantially. From the standpoint of delay, certainly such hits are extremely significant if the bridge itself is missed.

In Italy, it was found that the chances of securing a blockage are very high if heavy tonnages are dropped, as shown in the following figures:

	TONS PER RAID			
	Under 25	25-50	50-100	100-200
Mean Tonnage	20	36	73	164
Raids	3	13	11	8
% Hit	0	8	45	62
% in Which Bridge was Blocked by Being Cut or 50% Destroyed	0	8	27	38
% in Which Traffic was Blocked by Any Means	33	31	55	88

It will be noted that it is much easier to block a bridge by cutting approaches or damaging embankments than it is to cut or destroy the bridge itself. However, this is a small sample and is not set up so as to be statistically comparable with other studies.

In the Burma study, the effect of tactics is clearly shown. Overall, an average of 15.5 sorties per serious hit on the bridges was required; however, it took 26.4 high sorties per hit, 10.0 medium or low (1000 to 2500 feet), 12 dive sorties, and only 2.4 minimum level sorties.

A preliminary analysis of air attacks in Europe indicates that substantial delays can be achieved by bridge bombing. In 54 attacks which resulted in hits on or near bridges, an average of 6 days delay resulted before single track operations were restored. For bridges under 300 feet in length, the average was 4.4 days, compared with 7.9 days for bridges of more than 300 feet. An average of 7.3 days was obtained in 30 additional attacks for which no details as to type of bridge are available.

To assess the types of damage possible and their importance in terms of blockage, the following sample of results has been compiled; the information refers to effects of bridge attacks in France during August 1944:

I. MINOR DAMAGE

Type of Damage Resulting	Days to Repair for	
	Single Track	Double Track
Bridge intact; line cut; hit on embankment	1	-
Bridge intact; lines cut on both approaches	3	4
Minor damage to bridge; lines cut by severe cratering of embankment	3	5

I. MINOR DAMAGE (Continued)

Type of Damage Resulting	Days to Repair for	
	Single Track	Double Track
Decking of one span torn up by direct hit; line cut on N. approach	2	4
Glancing blow on side of central span damaged parapet and tore up line	1	3
Embankment cratered; lines cut	0	0
E. track impassable; decking holed at one end and bottom girder appears bent; W. track undamaged	0	14
Near misses damaged both abutments and one span; embankment cratered and lines cut	2	7
II. MAJOR DAMAGE		
3 E. spans demolished	21	36
N. span destroyed; remainder damaged	14	36
Severe damage to one span; train hit, cutting both lines	14	28
W. span cut and both halves hanging in river; center span deformed by direct hit; E. approach cut	20	40
One span hanging into water; damage to decking of another	10	20
Direct hit severed central span	5	10
Direct hits damaged 3d span and destroyed 7th span; 4th span damaged by glancing blow; 7th pier damaged; both approaches undamaged	14	21
3 spans completely collapsed; 1 span broken at center and sagging into river	30	50
One span dropped from piers; 2 spans badly damaged	7	-
2 spans destroyed; 1 pier damaged; 1 arch damaged; 1 arch destroyed; 2 center tracks damaged; roadbed damaged; all lines cut on approaches; train passing on bridge during attack severely damaged	7	30
Bridge torn from abutments and turned 15° from original position; E. end resting on embankment; W. end partly under water; E. approach badly cratered, cutting all lines; W. embankment & approach track damaged	28	50

It can be seen from the above that it is extremely difficult to keep a bridge out of service for long periods. Many technical elements are involved, but only a few will be mentioned here to indicate the nature of the problem. In England, it is reported that on bridges equipped with superstructures the bombs usually exploded in the top members without reaching the deck of the bridge. However, in the case of the Warren truss span, a bomb exploding in the top members might cause collapse; since they bear a large part of the total deadweight, any damage to them weakens the entire bridge structure.

Lift bridges are desirable targets because the lift machinery can be irreparably damaged if hit, thus preventing traffic from moving on or below the bridge. Length is also an important consideration -- the longer the bridge, the easier it is to hit and the more difficult it is to repair. In general, masonry bridges are easier to damage than steel bridges; in selecting targets along a line, other things being equal, masonry bridges are preferable inasmuch as they require a smaller expenditure of air effort.

The techniques of repair very. If a small masonry arch bridge is destroyed, it can be replaced with a timber trestle; six 10-foot spans could be erected within 48 hours, assuming that reserve materials and equipment are available. To replace a long high bridge, timber arches and masonry or timber supports might be used. In this connection, it is worth noting that height is extremely important; a bridge 60 feet high might take 2½ times as long to repair as one 30 feet high. The problem of obtaining piles of the right height is likely to be serious; splicing piles is slow but possible.

A study by the 15th Air Force indicates that, although steel bridges are more difficult to destroy than masonry bridges, they are also more difficult to repair. Thus, on steel bridges, with spans not over 100 feet, where trusses were sufficiently damaged to necessitate removal, the German Army's rate of repair averaged 7 feet per day, working in the daytime only; in contrast, on masonry bridges with the same limit on length of span, where arches and piers were completely destroyed over more than 200 feet, and where the height of the bridge was not over 30 feet, the German rate of repair averaged 11 feet per day, working in the daytime only. These figures do not include time required to get men and equipment to the site.

Other considerations include the height of the banks, character of approaches, depth of river, speed of flow, and type of river bottom. Shallow streams are relatively easy to trestle. If the banks are steep, repair methods are more limited and speed is reduced. Similarly, the efficiency of pile driving depends on the speed of the stream and the nature of the bottom.

In general, the most effective aiming points are the bridge piers. The supports, if hit, may drop two spans, whereas the superstructure, if hit, may drop only one span. The supports of the longest spans are most important.

Moreover, the lower the hit, the more difficult the repair job. If the piers can be hit in a deep, swift current (or at the bottom of a ravine), the work of reconstruction will be slowed down by collection of silt and by the inaccessibility of the foundation. It may be observed parenthetically that the Burma experience indicates the possibility of using floating mines against bridge piers; the procedure for wood pile bridges is to connect two floating mines with a cable, fill them with an incendiary mixture, and drop them upstream to drift down, catch, and burn under the bridge.

Despite the limitations of transferring performance records, in view of variations in bombing altitudes, types of planes, AA and fighter opposition, etc., some general magnitudes may be arrived at. Assuming medium level attacks on Japanese bridges with a 4% accuracy rate, assuming 8 hits with 500-pound bombs required to yield 6 days delay, and assuming a 4000-pound bomb load, a total of 250 bombs would have to be dropped by 25 planes to keep a bridge out of service for 6 days; this would mean 5 attacks with 25 planes -- a total of 125 sorties -- to keep a bridge out of service for one month.

The analyses of line targets indicate that possibly 10-15 sorties per day or over 300 sorties per month are needed to keep a line out of action. It appears, therefore, that bridges require a smaller scale of effort to achieve a given disruption in traffic.

C. Tunnels.

Railway tunnels fall into three broad groupings. "Cut and cover" tunnels are very shallow and hence are vulnerable to bomb damage from the surface as well as from internal blasts. Deep tunnels built with compressed air are usually found in sand, silt or clay; they are often lined with cast iron sections which may be disrupted by internal or external blast. Most important are the rock-driven tunnels. These are ordinarily difficult to damage by internal explosion because the method of construction, involving small blast charges, results in little or no loosening of rock adjacent to the tunnel. An explosion on the floor of the tunnel would destroy the tracks and blow a shallow hole in the tunnel floor, with some loosening of blocks in the roof and walls. Near the portals, pressure of the explosion might do more damage; if the portals are destroyed, the tunnel mouth will be filled, blocking the line until debris can be removed and the portal temporarily timbered. Where the bedrock is marl, marly shale, and thin-bedded sandstone, explosions at tunnel mouths have a good chance of causing the rocks to slump -- especially after heavy rains.

Tunnels in Japan have some special significance, not only because of their exceptional abundance, but also because rock structure in Japan makes the tunnel mouth unusually vulnerable. On the other hand, experience with earthquakes has forced attention to the problem of portal protection and presumably attempts have been made to support the entrances to tunnels.

One source states that the everyday variety of earthquakes "engender weaknesses which are latent in probably all Japanese tunnels but escape notice as a rule until they are revealed by the great earthquakes; those weaknesses then become apparent by (1) slides of side cuttings at approaches to the tunnel mouth, (2) slides and cave-ins over the tunnel collar, (3) breaks along fault zones of heavy or soft ground if present in tunnel interiors, and (4) stimulated water gush."

Insufficient data are available to permit an assessment of required bomb expenditure on tunnels. Some general observations are possible, however. First, the accuracy of bombing is likely to be less than on open lines -- not only because the aiming point is quite small but also because of possible difficulty in approach over rugged terrain. On the other hand, if the mouth is missed, blockage may be achieved by damaging the cuttings at the approaches and creating slides. Skip-bombing might overcome some of the technical obstacles involved, depending on the types of planes available.

In general, it appears that tunnels are a significantly better target in Japan than they were in Europe. However, it is uncertain whether they are better targets than lines or bridges. A few test raids should be undertaken to determine the specific merits of tunnel targets in Japan.

D. Area Isolation.

The bulk of the traffic flowing into a city consists of raw materials, fuel, and food; outbound freight is usually smaller in volume and consists of manufactured items at varying stages of processing. Isolating such an area from rail transport may have serious effects on the enemy potential.

This method of attack involves lines, bridges, cuts, tunnels, or embankments and the advantages and disadvantages are a composite of those attaching to the individual types of targets. In general, the problem of policing the damage is most serious. Moreover, motor transport may be used to handle the minimum needs of the area. To make this alternative less likely or feasible, it is desirable to make the cuts at points some distance from the city; to do this means to permit a substantial amount of local or shorthaul traffic by rail. The most effective method would be to maintain two or three rings of cuts but this becomes extremely costly.

Thus, cutting Tokyo off from all approaches within 20 miles of the center would require hitting and policing 21 lines. To achieve isolation at a distance of 40 miles, 19 lines would be involved. In the case of Nagoya, 20 lines are cut at a radius of 20 miles, 12 lines at a radius of 40 miles. To isolate Tokyo by two rings of 10 cuts each on open lines would require about 400 sorties per day by heavy bombers. A scale of effort of comparable magnitude would be required for attacks on bridges, cuts, etc.

It must be assumed that most of the vital plants in a city maintain stocks sufficient to last for at least a few weeks. Food requirements would probably be stored near the cities if such an attack were carried out. Furthermore, facilities for quick repair of damage and speedy improvisation of motor transport are more highly developed in and around industrial areas than elsewhere. Again, the likelihood that anti-aircraft defenses will be organized to maximum effectiveness means that the cost of such operations becomes relatively high.

E. Locomotives.

Locomotives may be attacked directly on lines or in roundhouses or more indirectly by attacking repair shops and locomotive building plants.

Locomotives on line are vulnerable to attack by fighters or bombers. The record of 1,476 R.A.F. sorties despatched from April 1942 through May 1943 against locomotives and trains shows that 29 locomotives were destroyed and 921 damaged, and that 476 trains were damaged. During this period, effectiveness increased substantially; during April-June 1942, 125 sorties damaged only 26 locomotives; in April 1943, 136 sorties destroyed 7 and damaged 106 locomotives, while in May 1943, 131 sorties resulted in 5 destroyed and 143 damaged.

Virtually all aircraft were fighters.

Although it is rare for a locomotive to be damaged so seriously by machine gun or cannon fire that it is not worth repairing, substantial disruption can be caused. During the period February-November 1942, the average repair time for locomotives damaged in France was 9 days, according to a British source.

Japan has about 6,000 locomotives. To be conservative, assume only 600 unserviceables and 5400 actives. Then, if a fighter attack puts a locomotive out of service for 5 days, 100 attacks per month means 500 locomotive-days lost per month, out of a total of 162,000 active locomotive-days. This is a very small reduction in total capacity (less than ½ of 1%).

Attacks on locomotives in trains have several desirable effects. First, the locomotive is damaged. Second, the line is tied up. Third, the freight and the cars are delayed. Fourth, the train may be derailed, with resulting damage to cars and track.

Roundhouses have some merit as a target because of the concentration of locomotives in and around the building. However, the enemy can disperse these concentrations and may provide alternative facilities for coaling and watering at important terminals. Running repairs could be made elsewhere. A typical roundhouse has a concrete foundation, brick walls, heavy wooden posts, and composition roofing; significant damage to the locomotives requires a direct hit on the shed with fairly large bombs. Some disruption may also be caused by hits on the turntable, power plant, or machine shop but the effects are not serious. In general, loss of these facilities tends to slow down operations somewhat.

Locomotive repair shops are usually large installations with heavy equipment and substitute facilities are not readily available. Moreover, they tend to be concentration points for locomotives. The important Omiya shops of the Imperial Government Railways, employing over 15,000 men in 1937, have the following structural characteristics:

	Body	Roof
Boiler shop	Steel & concrete	Asbestos slate
Boiler shop	Wood	Corrugated iron
Finishing & Boiler shop	Brick	Corrugated iron
Transformer station	Steel & concrete	Concrete
Erecting machine shop	Steel & concrete	Asbestos metal
Foundry	Steel & concrete	Yamato slate
Tube storehouse	Steel & wood	Corrugated iron
Smithy	Steel, concrete & brick	Corrugated iron
Pattern shop	Wood	Asbestos slate
Storehouse	Wood	Corrugated iron

In general, the more important structures are solidly built and involve the same scale of effort as other industrial targets. Destruction of vital machinery is difficult without direct hits or very near misses on the particular buildings housing it. Destruction of power plants may cause only temporary stoppage; it may be possible to operate with power from steam locomotives until other arrangements can be made.

Locomotive building plants are typical of heavy engineering works. Many such plants are engaged wholly or in part on the production of direct military items. Their target characteristics also are typical of other heavy industrial plants.

The basic consideration with respect to locomotives is that successful reduction in the enemy's motive power capacity cannot be achieved by concentrating on any one type of target. If locomotives are attacked only on line, the Japanese can concentrate on repair facilities. If we attack repair facilities as well, the Japanese can concentrate on new locomotive production. Thus, effective attack must include all types of locomotive targets. If fighter planes are available, engines on line become high priority alternate targets, especially for planes missing their original objective.

Fundamentally, locomotives are not important strategic targets in Japan. The locomotive position is not critical. Even if the supply became inadequate, the enemy can choose between running freight or passenger trains with the available stock. When passenger service is reduced to a minimum, the enemy can choose the types of freight to be moved. Concentration on motive power will ultimately result in slower operation, yard congestion, and a slowing down in industrial operations but the results are far-removed and the program of destruction is costly.

F. Freight Cars.

The Japanese railways operate about 120,000 freight cars. As in the case of locomotives, they can be attacked in several ways -- in trains and yards, or by destroying repair shops and car building plants.

Although cars are numerous, they are not readily destroyed and are easily repaired. They are much more easily replaced than locomotives but require about the same amount of effort to destroy a given number of units. Even though the Japanese freight car position is tight, a substantial number of cars would have to be taken out of service before war production could be significantly affected.

Cars in trains cannot be seriously damaged by fighter attack, except to the extent that locomotive damage results in derailment of the train. In this event, the key target should be the locomotive itself. However, a train containing loaded tank cars may be ignited, causing some damage to other cars and contents; as targets of opportunity, such trains make better objectives than trains of refrigerator or coal cars.

Repair shops have some concentrations of cars but most repairs can be made in the open if necessary. Japanese methods are extremely efficient and it is doubtful if the total number of cars at all repair shops exceeds 4,000; even if all were damaged or a major part destroyed, the overall effect on Japanese capacity would be insignificant. In any case, since the equipment of repair shops is simple, the structures can be easily replaced.

Classification yards have large concentrations of cars. In the larger yards, the average number of cars on hand might run to about 600 -- more at certain times of the day, less at others. To destroy 10% of the Japanese car supply in a short period of time would require 20 tremendous raids, virtually covering the entire track area with bombs. This is a practical impossibility. Small scale efforts can do little more than destroy a few and damage a relatively small number of cars. (See discussion of yards hereinafter).

Somewhat related to yards are general industrial areas and freight stations, where concentrations exist. Steel plants have extensive sidings on which many cars are likely to be found. In such cases, however, emphasis should be on attacking the industrial facilities themselves, with any damage to freight cars being considered as so much "bonus".

Freight car production is concentrated in a relatively small number of plants, buildings being typical of light industrial facilities. However, the nature of the materials and equipment needed for freight car manufacture is so much less complex and strategic than in the case of locomotives that effort expended on such plants would be comparatively expensive in terms of effect on the Japanese economy.

Attack on locomotives or cars will reduce transport capacity. However, destruction of both at the same rate involves waste motion; a given rate for either does just as much damage. If a choice were to be made, locomotives would be a much better target than freight cars.

G. Yards.

Although classification or marshalling yards are the nerve centers of a railway system, they do not rate very high as a strategic bombing target.

Military traffic represents only about 15% of the total tonnage originated in Japan. Much of this can move in solid trains without being broken up at classification yards. This traffic would be delayed only by difficulty in restoring through tracks -- a problem which is essentially the same as occurs in bombing open lines. Furthermore, much industrial traffic can be moved in large blocks to reduce the need for classification; this is especially true of bulk materials such as coal and ore. Again, important yards are located near industrial areas where the possibility of transshipment by truck is relatively great. Nevertheless, the bulk of the traffic would be delayed initially.

The enemy tactic would be to shift the classification work to other yards on the line so that cars would be handled nearly as efficiently as before; to minimize this possibility, several yards would have to be attacked simultaneously. In hump yards, destruction of the hump can be offset by using flat switching methods, if engines are available. If car retarders are damaged, car riders can be used. Hand operation can substitute for power switches. Damage to turnouts could delay operations but these can usually be replaced from inventories. Despite these makeshifts, total capacity of the yard would be substantially reduced for a considerable period.

Because of the concentrations of cars, serious difficulties may arise in clearing the yard. The need for heavy cranes may create somewhat more delay than would be obtained by bombing open lines. Supplementary advantages are the destruction of some locomotives, sheds, repair shops, and freight in cars. Yards located near ports tend to have a higher concentration of military traffic; tieing up such yards also ties up ships awaiting cargoes. Occasionally, yards can be important tactical targets. An attack made when several military trains are in the yard can kill a number of enemy troops and destroy munitions and supplies.

A study by the Ninth Air Force covering 7 raids on 4 yards is summarized below:

Yard	Date	Tons Dropped	% on Target	Size of Target (Acres)
Tergnier	9 Feb.	79	37.4	63
Hirson	6 Mar.	151	25.2	158
Hirson	25 Mar.	252	17.2	158
Creil	17 Mar.	122	14.8	118
Creil	20 Mar.	166	14.9	118
Creil	23 Mar.	274	25.4	118
Hasselt	8 Apr.	172	22.0	66

For all raids, the accuracy rate was 24.5%. Note that this small sample does not indicate improvement with increased target area. The conclusion of the study is: "Density of .75 tons per acre, as achieved on Hasselt, was the most efficient density obtained against marshalling yards during this period. In the case of Creil, the three attacks had a composite density of 1.17 tons which totally demolished the structures under attack and was definitely too heavy an effort. The individual attacks on Hirson and Tergnier were too light, as attested by the meager damage inflicted."

Analyses of three attacks on Verona by the 15th Air Force indicate that, of 2,861 bombs dropped, 31% fell within the target area. This included 9% which did no damage, 1% which damaged buildings, and 21% which damaged tracks and rolling stock. Damage to rolling stock varied from visible displacement or overturning to complete destruction in the case of direct hits. In the first raid, there were 1625 cars in the yard, of which 115 were damaged -- .41 cars for each bomb landing in the target area. On the other raids, the proportion was .57 cars damaged. If a car was more than 6 or 7 feet from the edge of a crater, it suffered no visible damage.

Through traffic was opened in 3 or 4 days, for all lines, but this was at the expense of leaving other damage untouched. After the first attack, repair work proceeded at the rate of 10 craters per day for 12 days, by which time the most inconveniencing damage (68% of the damaging bomb "incidents") had been repaired. For the next 22 days, work was at the rate of 2.4 craters per day until 93% of the craters were repaired. The remainder were repaired very slowly. After the last attack, repairs were at the rate of 10.5 "incidents" per day for 9 days. For the next 24 days, repairs were at the rate of 6.3

per day, and thereafter at the rate of 3.1 per day.

The relative importance of the various parts of the yard were assessed on the basis of the rates of repair. On through lines, repairs were begun immediately and pressed until service was restored. Work on the locomotive repair shop also began rapidly; as soon as the building was operating, the rate slackened. Work on the classification tracks was not pressed until the through lines and locomotive repair shop were functioning. The freight sidings and car repair tracks were attended to later. Virtually no efforts were made to repair the roundhouse.

One conclusion of the study is: "In general, heavy bomb densities are more effective per ton of explosive than light bomb densities. This applies so long as the bomb density is not so great as to lose effectiveness because of overlap of bomb strikes; the attacks on Verona show that a bomb density considerably in excess of one ton per acre is required before overlap becomes a significant factor."

A more generalized study of operations in Italy states: "Achievement of sustained blockage (10 days or longer) would require a density of 3 or 4 strikes of 500 G.P. bombs per acre throughout the area of a rail center. As a rough approximation, perhaps 500 despatched tons might be required to achieve this density."

The available evidence suggests that an effective raid on a yard requires about 1 ton of bombs per acre and that about 4 tons per acre must be dropped to achieve the necessary number of hits. Thus, with a yard of 100 acres in Japan, 200 planes carrying 400 tons would prevent through traffic from moving for 3 or 4 days and would prevent efficient classification for 2 or 3 weeks, possibly more.

To achieve the same delay to through traffic by attack on open lines a much smaller effort is necessary. To block a line to all traffic for a month requires about 300 sorties by heavy bombers. In the case of bridges, it was estimated that about 125 sorties per month were required to maintain blockage. In terms of tonnage, the relationship is 400 tons dropped for a yard and 250 tons for a bridge. Moreover, the attack on the yard does not stop all traffic on the line for an entire month. The advantage shown for bridges is therefore conservative.

In this connection, it is interesting to note that a study of operations between 22 October 1943 and 22 January 1944 in Italy shows about 428 tons of bombs were dropped for every complete blockage of a yard against 196 tons for every bridge blockage.

From both an operational and a strategic standpoint, it is better to drop a given tonnage in several attacks spaced a few days apart rather than to concentrate the effort on one big attack. Later attacks may destroy critical construction and repair equipment. Bomb damage may be assessed between attacks and the aiming point revised. Interference between units is reduced -- both in the matter of bad timing and in obscuration of the target by smoke. Finally, it has been suggested that the jobs of the navigator and bombardier can be simplified if the same crews return to the target.

H. Miscellaneous.

Signalling equipment, though important to railway operation in Japan, does not represent a desirable target. The aiming point is very small. Damage to a block section can be repaired quickly. If necessary, hand operated block signals can be substituted for electric. In general, although total train capacity would be reduced by a serious disruption in signalling, such disruption would be extremely difficult to achieve and would not seriously affect Japan's military strength.

Electric lines in Japan handle a heavy volume of freight and passenger traffic, primarily around important cities. Damage to electric lines could not ordinarily be so severe as to prevent at least some operation, either from alternate sources of power or else by prompt repair. Damage to generating plants is not likely to be so widespread as to cause complete stoppage. If electric power were completely cut off, several days would be required to restore operations to a reasonable working level by the use of steam; this is possible only if there is a considerable number of steam trains currently operating on the line, with the necessary coaling and watering facilities available. This is the situation in Japan, where most of the freight trains are steam operated while passenger trains are generally run by electric power. In summary, it appears that attacks on electric lines may produce longer interruptions than equivalent attacks on steam lines.

Destruction of passenger cars is of little strategic value. Even the ultimate effects of such attacks would be of minor significance to Japan's war potential.