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The Mallet Locomotive as a Factor in Railway Location

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THE MALLET LOCOMOTIVE AS A FACTOR IN RAILWAY LOCATION

BY

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THE MALLET LOCOMOTIVE AS A FACTOR IN RAILWAY LOCATION.

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INTRODUCTION

A.- THE MALLET ARTICULATED LOCOMOTIVE.- The articulated locomotive, compound or simple, is a locomotive having two sets of cylinders driving independent groups of wheels which support two sets of frames joined by a pivot joint or hinge. The leading set of frames, cylinders and driving wheels support the forward end of the boiler and swivel radially about the pivot connection giving the effect of a truck, and thus reducing the length of rigid wheel-base. The term 'Mallet' is now generally applied to all articulated locomotives of this type without reference to the system of compounding.

B.- IMPORTANCE OF MOTIVE POWER IN THE ECONOMICS OF RAILWAY OPERATION.- The importance of larger locomotives in economical operation was well understood by the late A. M. Wellington, and was ably discussed by him thirty years ago in his monumental treatise on "The Economic Theory of Railway Location". In this great book Wellington preached the doctrine of larger train-load as the way to economic railway operation[1]. Furthermore, he urged the use of larger engines with greater tractive power as a necessary means of effecting economic operation of passenger and

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1 Chapter V- "Economic Theory of Ry. Location"-Wellington.

freight trains, especially for freight trains. Like other of his earlier recommendations, such as air brakes and automatic couplers, the railways seemed to be slow in grasping the importance of these suggestions. At the present time, however, it is an axiom that economical operation demands the use of the fewest possible number of trains to handle a given traffic. The size of trains on almost all roads is only limited by the hauling capacity of the locomotives, which, in turn is claimed to be restricted by such conditions as stability of roadbed, weight of rails, rate of grades, degree of curves, speed required, gauge of track and amount of traffic. All of these restrictions, however, now seem to have been overcome to a large extent, if we may judge by the giant Mallet locomotives now in rather common use.

As time goes on the ever growing demand for increased transportation facilities is before us, and still the problem is not completely solved. The freight tonnage of the railways of the United States for the year 1900 was 516,432,217 tons, while in 1912 it was 998,282, 525 tons,* giving an increase of 91.3 per cent in twelve years. With the increased tonnage a constant growth in the number and weight of locomotives took place in order to meet the new demands. In 1900 there were 37,663 locomotives in use and in 1912 there were 62,262, of which 37,159 were freight locomotives. The tractive power of these locomotives in 1902 averaged 20,485 pounds per locomotive and in 1912, 28634 pounds, an increase of 39.7 per cent. The latter

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* Statistics of Railways. 1900-1912 . U.S. Bureau of Railway Economics. Bulletin 66.

figures, however, do not include the Mallet locomotives which in 1912 numbered about 534, and had an average tractive power of 76,502 pounds.

With the growth of locomotives, improvements were also made in the terminals and main tracks, for the purpose of increasing capacity for handling traffic. But it was not until the advent of the Mallet locomotive, an extraordinary type of engine, that it was generally conceded that 125 tons was not the limit of weight on the drivers which could be utilized in one locomotive on 90-lb. rails.

For many years the Consolidation had been the standard freight engine, but other types such as the Decapod, Mikado and Santa Fe began to find favor about 1905. The increase of several feet of rigid-wheel base in these new types of locomotives, however, proved a very serious obstacle in many ways in operation. Consequently, the railway officials had almost concluded that the solution to the problem of moving greater train-loads must lay in either widening the gauge of their roads so as to permit the building of stronger and heavier locomotives of the existing design, or in increasing the number of locomotives per train. The latter scheme was finally adopted by the railroads to such a degree that on many heavy grade divisions two or more locomotives attached to a single train were not uncommon.

However, this method of attaching extra engines to a single train was only a temporary and unsatisfactory expedient as the expense in operating these extra engines was usually excessive. To increase the gauge of 300,000 miles of road for

the sake of meeting the increased traffic demands was a solution which was out of the question on account of the vast expense, except as a last resort.

At this juncture the possibility of increasing the power and size of locomotives was again considered in minute detail. The maximum height and width of the locomotives had been reached, it was claimed, because of the limiting gauge, but growth of the engine through increase in length was still possible. While the railroad officials were in this dilemma, attention was turned to the Mallet design. The Mallet articulated locomotive had been used for over 20 years in France and other European countries, although no engines of that type had been built which even approached the weight and size of the articulated engines which were contemplated for use on the American railroads.

In 1904 the first heavy articulated locomotive of the Mallet type made its appearance on an American railroad. Its usefulness was very much in doubt at first, but this doubt was somewhat removed by the test of the engine in pusher service on the Baltimore and Ohio Railroad in January 1905. The result of the test gave evidence that the Mallet type of locomotive could perform the pusher work much cheaper than the Consolidation type previously used. As a result of this test and succeeding ones, over a thousand of these Mallets, more powerful and heavier than the first one, are now in use throughout the country.

C.- PURPOSE OF THE INVESTIGATION.- The purpose of this investigation is to ascertain what part the Mallet locomotive will be likely to play as a factor in future railway location

and relocation and improvement of existing lines. The principal points involved are the choice of ruling gradients and pusher gradients, avoidance of reduction of existing gradients, the relief of the congested condition of the freight traffic and the reduction of maintenance cost in low grade lines and pusher service.

CHAPTER I

HISTORY AND DEVELOPMENT OF MALLET LOCOMOTIVE.

A.- Early History of the Articulated Locomotive.

The Mallet articulated locomotive of to-day is not the result of a few years of investigation but is rather the culmination of numerous attempts during the last 80 years to build a successful locomotive of this type.

In 1831, Horatio Allen, an eminent American Engineer, designed the first articulated locomotive, which was named the "South Carolina". This locomotive was built by the West Point Foundry Company of New York. When the engine was completed, however, Allen found many errors which he afterwards spent much time trying to correct. The hardest problem was to distribute the weight of the locomotive over a number of wheels and still retain flexibility. The inventor evidently found at last that the problem was too complicated to solve by means of the limited appliances in use at that time, for he relinquished the attempt so ably begun.

In designing and building this articulated type of locomotive, Allen was trying to minimize or overcome the troubles incident to the other locomotives of that time, such as Stephenson's "Rocket", which was built in 1829 and was the first commercially successful locomotive. Some of these troubles were the lack of adhesion between the wheels and rails or lack of tractive power, and difficulties in passing around sharp curves.

When Allen failed to solve the problem, attention was then turned to improving the roadbed, strengthening the track,

and producing locomotives with a single pair of driving wheels. Thus the articulated idea was relegated to temporary oblivion.

There was practically no attempt made to continue the improvement of Allen's articulated engine until about 1861 when Robert F. Fairlie, an Irish engineer, designed an articulated locomotive which to this day bears his name. Robert Fairlie was an ardent student of narrow gauge railroads, especially in mountainous country where railroad building was expensive. Fairlie's idea was that the articulated locomotive would make transportation over such roads possible with minimum outlay for construction, since very high gradients could be utilized. The Fairlie locomotive was familiarly called the " double ender ", because it appears to be a combination of two independent locomotives the boilers of which were joined together back to back with a small firing space between. However, the two engines had separate frames, separate running gears and cylinders, with independent trucks which were free to swivel about the center pins on which the boilers rested. This type of engine proved too flexible for other than slow service and consequently its usefulness was wholly confined to winding mountain roads where the consideration of high speed was not important. It was found that even under such conditions, when the engine was taxed to its capacity, the drivers would often slip at critical times and the engine itself would oscillate from side to side, which, under these conditions produced constant leakage in the flexible steam pipes. Nevertheless, with all of these shortcomings, the demand for this Fairlie flexible articulated locomotive was large, and it was used to a great degree in several countries, especially in Mexico.

Modification of the Fairlie design was undertaken by Meyer, a German engineer, in later years, using one boiler instead of two. The arrangement of the double truck was practically the same as in the Fairlie engine except that the back and front engines were joined by a bar.

The introduction of this type of "Meyer-Fairlie" locomotive into this country was attempted by William Mason about 1880. Later he built the "Mason-Fairlie" double-truck locomotive, having one boiler and one set of driving wheels which swivelled, also a rear truck which carried the water tank and fuel on the rear extension of the locomotive. This engine was quite popular when it came out, and even to-day several of this type are used by foriegn railways. Little improvement in this type of locomotive was made until 1892 when the Baldwin Locomotive Works built one of these engines for the Sinnemahoning Valley Railway in this country, with compound cylinders. While this engine had the same faults as its predecessors, it paved the way, however, for the present Mallet type of locomotive.

The Mallet articulated type locomotive was first proposed in 1884, when Anatole Mallet, a Frenchman, who was then chief engineer of the Bayonne and Biarritz Railway of France, started an era of economics in locomotive building by perfecting the compound cylinder locomotive, and later, in 1887, bringing out the Mallet articulated locomotive for the Decaville R.R.. Mallet's first locomotive of this type was a two cylinder locomotive of Roentgen type built at Creusot for the Bayonne and Biarritz Railway. Mallet, in the two years of experimentation

with the two cylinder locomotive, found that it did not meet the service demanded, and finally he adopted the four cylinder tandem type. But before he got through working with the tandem type he built one in which the cylinders were coupled to a separate system of wheels operated independently, but with one supply of steam. Mallet's idea was either to use a rigid frame to connect the two or to articulate. The rigid frame locomotive, however, had been introduced in 1885 by De Glehn for the Chemin de Fer du Nord of France and so Mallet then devoted his thought to the articulated system. After much experimentation, he introduced the articulated frame which is a characteristic feature of the type which now bears his name.

The Mallet articulated locomotive was later placed on exhibition at the Paris Exhibition in 1890. This engine was only a model, weighing 11 1/2 tons, of the 0-4-4-0 class and was operated on a track of 2 ft. gauge in the exhibition grounds. The next Mallet appeared in 1891 on the Gothard Railway of Switzerland; weighed 95 tons and was of the 0-6-6-0 class. As early as 1888-89 the Swiss Central Railroad ordered the construction of six four-axle articulated compound engines each weighing 60 tons. These locomotives were built by Maffei of Munich. The engines were placed in service between Sissach and Olten where gradients were as steep as 2.7 per cent. A tunnel 2,520 meters in length was located on this declivity. These engines gave such excellent results as to induce the company to give another order of ten more of the same type. The popularity of this class of locomotive in the freight service in Europe was so great that in 1902 over 500 engines of this Mallet type were said to be in

use.

Mallet, in his later experiments of adapting his designs to sharper curves, in competition with such engines as theBavaria by Maffei of Munich; the Wiener-Neustadt, by Gunther of Vienna; the Seraing, a Belgian engine, by John Cockerill and the Vindobona by the Vienna-Glognitz Railroad*, inaugurated several important improvements which were destined to convert the articulated locomotive into one of very practical achievement. Instead of allowing the rear set of driving wheels to swing about a center pin, he secured them laterally in line with the boiler, to which he fastened the high pressure cylinders and delivered steam through fixed pipes, thus avoiding the use of one set of flexible steam and exhaust pipes. This new arrangement gave a substantial foundation to which the frames of the forward set of driving wheels were hinged and avoided the lack of stability which perhaps was the most serious defect in the Fairlie system. The swing of the forward engine of the Mallet locomotive was thus limited to suit requirements and the entire driving wheel-base of the engine was used to insure transverse stability.

When Mallet designed this type of locomotive, he had in mind only narrow gauge roads with comparatively light traffic. He probably did not contemplate adapting his idea to heavy engines of 300 to 500 tons, as the weight of European Mallet locomotives usually ranged from 25 to about 110 tons only. Thus the problem of applying this engine to American conditions was yet unsolved.

The idea of introducing the Mallet type of locomotive

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* Proceedings of A.S.M.E. July 1893, Vol.XLV.

into this country originated in 1898 with Mr. L. F. Loree, who was then President of the Baltimore & Ohio Railroad. The initial drawings of this American type of Mallet were made in 1902, and in 1904 the first heavy Mallet locomotive was completed and placed on exhibition at the St. Louis Exposition. The honor of designing this engine, which weighed 120 tons, belongs to C. J. Mellin of the American Locomotive Company.

B.-COMPARISON OF THE EARLY TYPES OF ARTICULATED LOCOMOTIVES.

In comparing the early types of articulated locomotives only two need be mentioned, the Fairlie and the Mallet, referred to in the foregoing pages. The latter has proved to be superior in almost every way. With equal weight on drivers and equal length of rigid wheelbase, the Mallet has proved to have a greater resisting moment to overturning than the Fairlie. No high pressure steam is carried in flexible pipes on the Mallet engine and this tends to avoid leakage at the joints which obstructs the view of the engineman during the cold weather. There is, moreover, great economy of fuel in the Mallet through the introduction of compound cylinders. Another advantage which the Mallet locomotive derives from compounding is the lessening of the tendency of the drivers to slip when starting a long heavy train or when ascending heavy grades. This trouble cannot so readily occur with the Mallet type locomotives, as in the event of slippage, the locomotive quickly recovers itself through the distribution of steam from the two sets of engines. Moreover, besides eliminating an undesirable

degree of transverse flexibility the Mallet locomotive simplifies the design and operation by having one boiler instead of two.

C.-DEVELOPMENT OF THE MODERN HEAVY ARTICULATED LOCOMOTIVES.

When the first heavy Mallet articulated locomotive appeared in this country, there immediately arose a doubt in railway circles as to the feasibility of such a huge moving powerhouse.

Predictions of failure were frequently made, particularly by those connected with the motive-power departments. The situation was much like the unfavorable comment on the Consolidation locomotive, when it was proposed in 1872 by Alexander Mitchell of Wilkes-Barre, Pa., a former Master Mechanic and Division Superintendent of the Lehigh Valley Railroad. The locomotive manufacturer even went so far in this instance as to refuse to build the Consolidation type of engine for fear of failure. Finally it undertook the task with a strong protest, insisting that its relation in the undertaking should not be divulged. The engine was designed to pull heavy train-loads of coal over the Wilkes-Barre mountains on a grade of 90 feet to the mile. After a trial, however, this Consolidation engine demonstrated its usefulness to such an extent that for the past 25 years it has been the standard freight engine in this country. The Mallet type locomotive, however, was a little more fortunate in its reception than the first Consolidation locomotive, notwithstanding the skepticism with which it was at first received.

The first Mallet locomotive in this country, which was mentioned previously, was built for the Baltimore & Ohio Railroad.

It weighed 120 tons and was of the 0-6-6-0 type. It had no front and rear trucks, because the designer believed that without trucks it would better operate over the curved track. But when the second Mallet came, which was built for the Great Northern R.R., it was of the 2-6-6-2 type, and trucks were introduced by the builder, The Baldwin Locomotive Works. The builders reasoned that the front trucks would steady the end of the locomotive and would assist in guiding the engine around curves as well as reducing the wear of flanges on the driving wheels. The latter change, as soon as thoroughly tried out, was acknowledged to be a great improvement for all conditions other than for switching at low speed.

The next engine to mark a stage in the development of the Mallet locomotive was that built for the Atchinson, Topeka & Santa Fe Railroad, a 2-8-8-2 type for freight service. A 4-4-6-2 type also was constructed for passenger service. Here we see the Mallet used not only for freight service, but also, for the first time in this country for passenger service. The Santa Fe used this engine for passenger service on the Belen Cut-off in Arizona on 1.75 per cent grade, with speeds of 25 to 30 miles per hour. The Southern Pacific also adopted a 2-6-6-2 oil burning type, for passenger service on 2.2 per cent grades. The Central Pacific has 12 of these Mallets which are hauling passenger trains on grades of 116 ft. per mile, 40 miles long, on the Sacramento Division, in California.

The development of heavy Mallet locomotives has progressed so rapidly in the last few years that the record of being "the heaviest locomotive in the world" has been held by a number of Mallet engines, each in turn relinquishing it to a new one.

The following table gives an idea of the rapid increase of weight of American locomotives from 1898 to 1913.

TABLE I.*
Increase in Weight of American Freight Locomotives.

Railway	Year	Class	Per Driving wheel	Weight On Drivers	Engine	Engine and Tender
Union	1898	2-8-0	26000	208000	230000	334000
Illinois C.	1899	4-8-0	24150	193200	232000	364900
P.B. & L.E.	1900	2-8-0	28125	225000	250300	391400
A.T.& S. F.	1902	2-10-0	23200	232000	259800	383800
A.T.& S.F.	1904	2-10-2	23458	234580	287240	453000
B&O	1904	0-6-6-0	27833	234000	334000	477000
So. Pacific	1909	2-8-8-2	24634	394150	425900	596000
Del & H	1910	0-8-8-0	27750	444000	444000	611800
A.T.&S.F.	1911	2-10-10-2	27500	550000	616000	850000
Erie	1913	2-8-8-8-2	28207	761600		853050

The advantages of the Mallet engine in freight train operation have become so apparent that many railway companies have undertaken to convert existing engines of the ordinary types to the Mallet type. Some of the railways which have thus converted old engines are the Santa Fe, Chicago Great Western, Great Northern and the Canadian Pacific Railroads. The Santa Fe Railroad is one of the greatest users of Mallet engines. Many of the older types like the Decapod, Prairie and Consolidation engines were converted into Mallets by this company. By combining two locomotives, each of which was formerly mounted on a single set of drivers, into one Mallet locomotive mounted on two sets of drivers, or by adding a new front section to an existing locomotive, the old locomotive is utilized in the production of the new. The Santa Fe Railroad found through experience in thus converting 14

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* Eng. News- May 4, 1911.

Mallets that conversion by adding a new front is more satisfactory and more economical than combining two existing locomotives into a single Mallet. It is claimed that Mallet locomotives converted from the older types of freight engines have increased the efficiency of the older type from 50 to 75 per cent.

CHAPTER II.

EXTENT OF PRESENT USE OF MALLET LOCOMOTIVES.

A.-Use of Mallet Locomotive in European Countries.

The Mallet articulated locomotive was first presented to the European countries, as prevoiusly indicated, in the year 1884 by its inventor, Anatole Mallet, after years of study and research Its value for railroad work on heavy grades and sharp curves was scarcely realized, however, until 1887 when a 12-ton engine of this type was constructed for the Decaville Railroad of France. The engine was built for track of 0.60 meter gauge and to pass around curves of 15 to 20 meter radius. The trial of this first engine was a complete success, and, soon after, demands for this typé of engine to be used on tracks with gauge of 0.60 of a meter, 0.75 of a meter and 0.80 of a meter were numerous. Although the practical value of this Mallet engine was not fully demonstrated until 1889 when six such engines, which were built for the Decaville Railroad, had performed service to and from the Universal Exposition at Paris,France.

In 1888-89 the Swiss Central Railway, after learning the practicability of the articulated locomotives, ordered through the Maffei Works, of Munich, the construction of six four-axle articulated compound engines, each weighing 60 tons. The performance of these six engines in passenger and freight service on heavy grades and on curves of small radius gave such excellent results that

another order of ten engines of the same model was made.

This marked the beginning of the use of the Mallet articulated locomotive in Europe. Its popularity was slight at the start, but it soon won the favor of the railways after numerous demonstrations. Most of the Mallet engines which were used in France, Germany and other European countries weighed from 25 to 110 tons only, but in England they were somewhat heavier, ranging up to 160 tons. The Mallet has proved its usefulness to the European railways so conclusively that its use is becoming more and more common. In 1902 over 500 engines of the European type were in use while in 1914 the total is claimed to have been no less than 2000. The American heavy articulated locomotive has been used on a few of the European railways during the past several years and is reported to have given satisfactory service.

B.- USE OF MALLET LOCOMOTIVE IN THE UNITED STATES.

The adoption of the Mallet in the United States, as was in the case in Europe, was slow at the beginning. But when the Mallet began to find favor throughout the country, it was developed with such rapidity as to almost overshadow the older designs. In 1905, a year after its appearance, the Mallet type was not seriously considered in this country for general service, Nevertheless, it was gradually winning its place in the pusher service and on very heavy grade lines. In explanation of this slow adoption numerous answers may be given, but probably the best one is

that the Mallet made its appearance somewhat in advance of its time.

It is of great interest to note that the great possibilities of the Mallet locomotive on American railroads was early recognized by Mr. James J. Hill who believed that the use of the heavy articulated locomotive would relieve the congestion of traffic on the mountain divisions of the Great Northern and the Northern Pacific Railways. Mr. Hill established his belief by ordering five Mallet engines in 1905, immediately after the test made by the Baltimore & Ohio R.R. A very important result of the performance of these five engines was that the Mallet locomotive, in addition to heavy pusher work, was found to have great advantages for heavy hauling in low grade road service.

In 1905 only six Mallet locomotive were in use in the United States. In 1912 the number had grown to 534*, with an average tractive power of 76,502 pounds, scattered over 32 of the leading roads in the country. In 1914 the number increased to 929, not including the converted Mallets. With such a large number in use and such a rapid rate of growth we have abundant evidence of the confidence of our railway managers in the Mallet type of locomotive. The possibilities of this type of motive power are illustrated in the case of the Santa Fe Railroad, one of the most extensive usersof the Mallet, which road is now using Mallet engines in freight service for the entire main line between Chicago and the Pacific Coast.

The number of Malletsis still growing and its increase

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* Railway Statistics.-I. C. C. Report of 1912.

is due to a better understanding of its usefulness un pusher service and general road work. It is rapidly replacing the Consolidation engine in pusher service, and it is also taking an active part in the movement of freight on low grade roads where the congestion of freight traffic is a serious problem.

The Consolidation engines, once the pride of the freight train service, and standard for the past twenty-five years, are gradually finding themselves being converted into Mallets or being relegated to the switching service. The Decapod (2-10-0) and the Santa Fe (2-10-2) types are still in limited use.

Another of the ordinary or rigid-base types of freight locomotives which is now extensively used is the Mikado (2-8-2), an offspring of the Consolidation type. This type is a contemporary of the Mallet. The general opinion seems to be that the Mikado has reached its limit of size, having an axle load of 60,000 pounds, which is considered about the maximum load possible with present track conditions.

The following table shows the number of the Mallet, Mikado, and Consolidation locomotives built in the United States from 1904 to 1914 inclusive.

It is of interest to note in Table II that these three classes of freight locomotives, excluding the figures of 1908, where the abnormally low percentage is due to the financial panic of 1907 formed an average of 40.1 % of all engines built since 1904. From Table III we see that the freight locomotives averaged 59.45% of all the engines since 1908.

TABLE II[1]

Growth in Number of the Three Principal Types of Freight Locomotives in the United States.

Types of Locomotives

Year	Loco. built for every year	Mallet	Mikado	Consolidation	Total of 3 types	per cent of the total
1904	2538*	1	35	837	873	34.5
1905	6265	5	92	1499	1596	25.5
1906	5642	8	116	1866	1992	35.3
1907	3482	81	5	1145	1231	35.3
1908	1182	13	20	80	113	9.5
1909	3352	170	48	11o1	1319	39.3
1910	3787	240	104	1379	1723	45.6
1911	2850	112	590	577	1279	44.8
1912	4515	168	1309	858	2335	51.6
1913	3467	72	796	823	1691	48.9
1914	1265	59	333	166	558	44.3

By taking the figure of Table II and III, the Mallet, Mikado and Consolidation engines make up about 70 % of all the freight locomotive in use.

TABLE III[2]

SUMMARY OF EQUIPMENT IN SERVICE ON JUNE 30,1912.
(Freight Cars.)

Year	Passenger	Freight	Switching	Unclassified	Total in service	Per cent of Frt. loco. each yr.
1912	14263	37159	9529	1311	62262	59.6
1911	14301	36405	9324	1297	61327	59.4
1910	13660	34992	9115	1180	58947	59.4
1909	13317	33935	8837	1123	57212	59.3
1908	13185	33655	8783	1110	56733	59.5
average	13745	35229	9118	1204	59296	59.45
av. %	23.2	59.5	15.3	2.00	100	

1 - Compiled from the Ry. Age Gaz.
* - Represents passenger and freight locomotives.
2 - Compiled from the I.C.C. report of 1912.

The number of Consolidation engines, as shown in Table II is rapidly decreasing, and the Mallet and Mikado types are gradually increasing. The slow increase in numbers of the Mallet as compared to the Mikado is probably due to the large first cost of the locomotive and to a limited knowledge of its significance in road service.

The approximate cost of a Consolidation engine varies from $13,000 to $ 18,000, for a Mikado from $18,000 to $30,000, and for a Mallet from $30,000 to $45, 000. The following table shows that the cost per pound of tractive power of the three classes of engines varies about 7 cents.

TABLE IV

COST OF THE THREE PRINCIPAL TYPES OF FREIGHT LOCOMOTIVES.

Type	Tractive Power per Engine	Average Cost per Engine	Average Cost per pound of tractive power
Mallet	76,502	$37,500	$0.4902
Mikado	46,122	21,500	0.4661
Consol.	36,911	15,500	0.4191

The disadvantage of the Mallet in first cost is more than offset by the saving in operation, as will be shown later.

The following table gives an idea of the different wheel arrangements of the Mallet locomotive now in use. The most common type of wheel arrangement is the 2-6-6-2 .

TABLE V*

TYPES OF MALLET LOCOMOTIVES IN USE.

No. of Types	Number in Use	Wheel Arrangements.
1	32	2-6-8-0
2	28	0-6-6-0
3	2	4-4-6-2
4	126	2-8-8-2
5	526	2-6-6-2
6	53	0-8-8-0
7	32	2-6-6-0
8	2	2-4-4-2
9	14	2-10-10-2
10	52	2-8-8-0
11	7	0-4-4-0
12	1	2-8-8-8-2 (Triplex)

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* Compiled from the Ry Age Gaz.

CHAPTER III

RESULTS OF TESTS ON OPERATION OF MALLET LOCOMOTIVE.

A.- Tests in Pusher Service.

1.- Baltimore and Ohio R.R.

In the first Mallet pusher service test, which was conducted by the Baltimore& Ohio Railroad in 1905, the results obtained were rather startling to the skeptical railway men who had at first predicted the failure of this new type of engine. The test took place on a 60 mile stretch of track between Connellsville and Sand Patch, Pa., on a 0.965 per cent ruling grade. When going up the 0.965 % grade, the Mallet was assisted by one of the regular Consolidation locomotives and on all other portions of the line where the gradients were 1.0% or less for a distance of 2 miles the Mallet locomotive handled the train alone.

The following data show the actual results from the performance of the locomotive for the three and one-third year period ending May 5, 1908.

TABLE VI.*
Performance of Mallet Locomotives.
Baltimore & Ohio R.R.

	Freight Service Mileage		
	Road	Helper	Total
Engine crew or construction mileage(Basis 6 miles/hr.	1798	139104	140902
Locomotive or Actual mileage	1798	76601	78399
Time avaiable for Trans. Dept. use		1027 days or 84.5 %	
Time unavaiable " " " "		189 days or 15.5 %	
Water used per lb. of coal consumed		6.23 lbs.	

* Am. Ry M.M. Ass'n Proceedings- VolXLI -1908.

TABLE VII*

COST IN CENTS PER MILE RUN.
Baltimore & Ohio R.R.

For	Cost on basis of Constructive mileage	Actual mileage
Engine crew hire ------------	10.16	18.27
Fuel -----------------------	9.30	16.71
Repair ---------------------	4.96	8.92
Wiping, hostlering & dispatching	0.89	1.60
Lubricating, oil, grease, waste	0.51	0.91
Water ----------------------	0.45	0.82
Sand, illuminating oils and other supplies --------	0.29	0.51
Total Cost -----------	26.56 ¢	47.74 ¢

* Am.Ry. M.M. Ass'n. Proceedings-Vol XLI -1908,Page235.

The actual mileage includes only the road miles made by the locomotive and does not provide for the time that it was crewed and waiting for trains, working around terminals and switching, a considerable portion of which occurs in helper freight service and for which an allowance is made in the constructive mileage.

Besides establishing the practicability of the Mallet locomotive this test showed that the Mallet consumed considerably less fuel and water per ton-mile than the two Consolidation simple locomotives which it replaced.

2.- Erie Rialroad.

Three Mallet articulated duplex compound helper freight locomotives were put into service on the Erie Railroad during September 1907. These three Mallets replaced nine heavy Decapod and Consolidation locomotives, each with tractive power ranging from 35,560 to 40,000 pounds. The performance of the three Mallet locomotives for the six-month period ending March 31,1908, is

shown in the following data*:

Total actual locomotive mileage ---------------	31,763
Total tractive power mileage ------	3,011 ,132,400
Average cost for maintenance per locomotive mile --------------	12.86 cents
Average cost for maintenance per 10,000 tractive power miles	1.36 cents

3.- Great Northern Railway.

The Great Northern Railway is probably the most extensive user of the Mallet locomotives to-day, having 103 of these powerful machines in service. In 1908, it had 67 Malletsof which 22 of the larger or helper freight type were used on the mountain grades on the Cascade Division and 45 of the smaller or road freight type on the districts where the maximum grade varies from 0.60 % to 1.0 %.

The cost per actual road mile for five of the helper freight locomotives, which were in service from November 1906 to March 1908 has averaged as follows[1]:

	Cost per actual road mile for 5 helper engines	
Engine crew hire, wiping, hostlering and dispatching ---------------	27.06	cents
Fuel ----------------------------------	55.22	"
Repairs -------------------------------	9.83	"
Lubricating oil, grease and waste -----	1.76	"
Sand, illuminating oil & other supplies	0.39	"
Total Cost ----------------	94.36	cents
Cost per actual mile per engine	18.875	"

The other twenty-five of the road freight locomotives were put into a 201-mile continuous trip service from November 1906 to June

.* Am. Ry. M.M. Ass'n Proceedings Vol XLI , 1908.
1. Am. Ry. M.M. Ass'n Proceedings Vol XLI , 1908.

30, 1907. The cost per actual road mile per locomotive has averaged as follows:

Cost of repairs per mile -------------------- 6.72 cents
Coal consumed per 100 ton-miles excluding weight of locomotives ----------- 19.18 pounds

Since the use of the Mallet, the freight train gross tonnage has increased on several divisions as follows:

1.-Cascade Mt. Division: increased from 1050 to 1450 tons
2.-Leavenworth, Wash. ,to Spokane, Wash: increased from 1000 to 1450 tons
3.-Whitefish, Mont. to Havre, Mont. increased from 1300 to 1700 tons
4.-Williston, N.D. to Minot, N.D.; increased from 1600 to 2200 tons

The Mallets have hauled a 35 per cent increase in freight train gross tonnage and have eliminated congestion in yards which previously accompanied the use of Consolidation locomotives.

The coal consumption averaged 14.3 pounds per 100-ton miles as compared with 28 pounds as consumed by one Consolidation type locomotive. This gives an approximate saving of 49 per cent of fuel. On this district between Minot, N.D. and Williston, N.D. the results of a sixty-trip test show 11.04 pounds of coal consumed per 100-ton miles westbound and 9.27 pounds of coal consumed per 100-ton miles eastbound. The performance of the Consolidation locomotives over the same district for the fiscal year ending June 30,1907, averaged 19.25 pounds of coal per 100-ton miles, showing a saving of approximately 47 % in fuel consumption.

Less trouble has been experienced in the handling of the heavier trains on the mountain districts and less difficulty has been experienced in the trains breaking in two as compared

with the simple Consolidation type locomotives.

The cost for repairs per mile run was found to be higher than for the simple Consolidation locomotives, but on the basis of 100-ton miles it is materially reduced.

An interesting comparative performance table was compiled by the Committee on Mallet Locomotives of the American Railway Master Mechanics' Association in 1908 as shown in Table VIII. It compares the results of the various tests which were conducted by the different railroads in the United States.

4.- Chicago, Milwaukee & Puget Sound Railway.

The Chicago, Milwaukee and Puget Sound Railway has Twenty-five Mallets of the 2-6-6-2 type. They are used on grades ranging from 1.0% to 2.4%, with speeds from 6 to 8 miles per hour. Fourteen of these Mallets are used in pusher service, some are used in regular train service on the C.M. & La Crosse Division and some in transfer and hump yard switching service.

A test was conducted on a 91 mile stretch of line with ruling grades of 0.50%, except about 1½ miles with a grade of 0.67%. The first run was made in January 23, 1911. The test showed an economy of about 21.0 per cent in fuel and water over simple engines in the same service.

5.-Chesapeake & Ohio R.R.*

As a result of a test comparing the Mikado type and the Mallet type locomotives, the Chesapeake & Ohio R.R. bought 24 Mallets instead of Mikados to be used on the road service on

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* Ry.Age Gaz.-April 5, 1912.

TABLE VIII.*

Performance of Mallet Articulated Compound Steam Locomotives

	B.& O.R.R.		Erie	G.N.R.R.	G.N.R.R.	G.N.R
1-Trip starts at	Connell-sville	Rock-wood	Susque-hana	Clancy	Leaven-worth	Havre
2-Trip terminates at	Rockwood	Sand Patch	Summit	Moodville	Spokane	Cut Bank
3-Length of trip in miles	44.2	15.6	8.5	47.93	197.37	128.6
4-Over all time of trip including delay	5 hrs. 12 m.	4 hrs. 1 m.				
5-Actual running time	4 hrs.	1 hr. 45 m.		5 hrs. 15 m.	15 hrs. 30 m.	10 hr 40 m.
6-Actual running speed M.P.H.	10.5	8.51		9.1	12.8	12.5
7-Ruling Gradient	.965%	1.875%	1.47%	2.2%	1.0%	1.0%
8-Ruling Curvature	9- 0	7 30	5 0	10 0	10 0	4 0
9-Number of loco. in train						
Mallet ---------	1	1	1	1	1	1
Consolidation --	0	1	1	0	0	0
10-Location of loco. in train						
Mallet ---------	Pull'g	Push'g	Push'g	Pull'g	Pull'g	Pull'g
Consolidation --	0	Pull'g	Pull'g	0	0	0
11-Average weight of loco. in working order, net tons						
Mallet ---------	225.0	225.0	268.36	208.54	208.54	208.54
Consolidation --	0	154.5	155.39	0	0	0
12-Weight of cars and lading, net ton	2370	2415	2850	700	1450	1700
13-Total weight of loco., cars and lading in train, net tons -----	2595	2794.5	3273.74	908.54	1658.54	1908.54

Continued to page 28a.

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* Proceedings . Am. Ry. Master Mechanics' Ass'n. page242.

TABLE VIII Continued.

	G.N.R.R.		G.N.R.R.	N.P.R.R.	N.P.R.R.	C.B.&Q.R.R.
1.----------	White-fish	Essex	Delta	Helena	Livings-ton	Browning
2.----------	Essex	Summit	Leaven-worth	Bloss-burg	Bozeman	Baders
3 ---------	50.03	18.26	108.75	21.0	25.5	3.4
4----------					1 hr. 52 m.	
5----------	7 hrs.5 m.		11 hrs. 15 m.	4 hrs	1 hr. 36 m.	
6 ---------	9.6		9.8	5.0	8.2	12
7.---------	.80%	1.8%	2.2%	2.22%	2.2%	1.15%
8 --------	10 0	10 0	10 0	11 0	11 0	4 0
9-Mallet -	1	2	2	1	1	1
Consolida-tion	0	0	0	1 (Mikado)	1 (Mikado)	1 (Prairie)
10-Mallet-	Pull'g	Pull'g &Push'g	Pull'g &Push'g	Push'g	Push'g	Push'g
Consolida-tion	0	0	0	Pull'g (Mikado)	Pull'g (Mikado)	Pull'g (Prairie)
11-Mallet--	236.14	236.14 (each)	236.14 (each)	236.39	238.39	238.39
Consolida-tion-----	0	0	0	(Mikado) 186.79	(Mikado) 186.79	(Prairie) 166.64
12.--------	1700	1700	1450	1350	1400	2800
13.--------	1936.14	2172.28	1922.28	1775.18	1825.18	3205.05

the Hinton division.

A test of a Mallet and a Consolidation engine showed a saving of 5.70 cents per 1000 ton-miles or 37.55% in the cost of hauling freight traffic in favor of the former. The Mallet pulled 3200 tons up the ruling grade while the Consolidation, with the help of a pusher pulled 2250 tons. The saving in fuel was 43% per ton-mile. With the installation of 25 Mallets on the division mentioned, 44 Consolidation engines were displaced, which resulted in a reduction of 27.6% for engine crews and 42.6% for train crews. The reduction of 5 cents per 1000 ton-miles in the cost of operation for 41 daily freight trains would mean a saving of over $75,000 annually.

6.-Delaware & Hudson Railway.

A test of Mallet locomotives was conducted on the Delaware & Hudson Railway on grades ranging from 0.68% to 1.36% for a length of 6 miles. The total rise in 19 miles was 945 ft. or an average of about 0.94%, uncompensated. In addition to the grade the road is very crooked, having 83 curves from 1 degree to 6 degrees 30 min..

The average results of four runs with two classes of E-5 (2-8-0) type and eight runs with the Mallet, four with each of the 0-8-8-0 type are shown in Table IX.

The results show that one Mallet performed almost exactly the same amount of work as two of the 2-8-0 type engines with a saving of about 44% in coal and 27% in water. Since the coal used on the Mallet was not as expensive a grade as that used on the Consolidation engines,the results are all the more striking.

The six Mallets replaced 12 Consolidation engines without sacrificing any tonnage and made a considerable saving in engine crew and train crew wages.

TABLE IX.*

Mallet Tests on Delaware & Hudson R.R.

No. of locomotives	2	1
Class	E-5	H
Type	44.8	45
Cars in train	30.3	30.1
Handled by puaher	2297.3	2276.6
Actual tonnage of train	1504	1490.8
Pound of coal per hour per sq.ft. grade area	55.8	57.9
Coal burned per 1000 ton-mile	.349	.196
Cost per 1000 ton-miles	.768	.431
Gallon water used	25288	18440
Pounds of coal burned	38148	21258
Miles per hour average	11	10.22
Percentage moved by pusher	65.99	65.48

* Am. Engr. & R.R. Jour. Sept. 1910.

7.-Norfolk & Western Railway.

This test, which was made by the Norfolk & Western Railway on a division where the maximum grade is 2.0%, was between a Mallet of the 0-8-8-0 type and a class M_2 twelve-wheel type engine.

The test was made on the division between Roanoke and Christianburg, a distance of 29½ miles, of which 12 miles have a continuous mountain grade of 2.0% maximum, averaging about 1.32% for the 12 miles. The result showed that one Mallet could haul a train of 1180 tons up the maximum grade of 2.0% , where as formerly a twelve-wheel engine of the heaviest type and a Consolidation locomotive working together were required. The Mallet pulled 50 per cent more cars than her competitors and increased the tonnage over the twelve-wheel engine by 44.3%. The coal consumption of the Mallet engine per 1000 ton-miles was 36 per cent less than

that of the two engines mentioned.

Another test which the Norflok & Western R.R. made was between two Mallets, one 0-8-8-0 type and the other 2-8-8-2 type. The general dimensions of these two locomotives were as follows.

TABLE X.*

Dimensions of Two Norfolk & Western R.R. Mallet Test Engines.

Type of engine	0-8-8-0	2-8-8-2
Engine No.	993	998
N & W Classification	X-I	Y-I
Rigid wheel-base	15ft. 6 in.	15ft. 6 in
Total wheelbase, engine & tender	72ft. 10in.	83ft 1½ in
Total length, engine & tender	88ft.11¾in.	92ft.5¾ in
Weight on drivers	376800 lbs.	370000 lb
Total weight	376800 lbs.	400000
Diameter of drivers	56 in.	56 in
Cylinders, inches	24½x39x30	24½x39x30
Steam Pressure	200 lbs.	200 lbs
Tractive effort	85000	85000
Valves	Piston, slide	Piston
Heating Surface	5388 sq.ft.	5895 sq.ft
Grate area	75 sq. ft.	75 sq.ft
Exhaust nozzle	6 in. dia. 3/8in. bridge	7 in.dia. ¾in. bridge

A summary of the average results of the tests shows clearly that the 2-8-8-2 engine was superior only in the item pertaining to boiler performance. As far as engine performance is concerned, the 0-8-8-0 handled 9.8 % more cars and 3.6 % more tonnage, at an increased speed of 19%. The consumption of coal per 1000 ton-miles on the two locomotives did not differ greatly, although there was a slight difference in favor of 0-8-8-0 engine.

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* RY. Age Gaz.-May 19,1911.

TABLE XI*

Summary of Average Results on the Norfolk

and Western Railway.

	Average of six trips Eng. 2-8-8-2	Eng. 0-8-8-0	Per Cent in favor of Eng. 2-8-8-2	Eng. 0-8-8-0
Boiler pressure	191.3	193.2	----	----
Water supplied boiler, lb.	108450	97582	----	----
Coal, total lbs.	12617	12467	----	----
Ratio. water to coal	8.66	7.83	11.0	
Equivalent evaporation per sq. ft. H.S. per hour	8.42	9.70	----	15.2
Equivalent evaporation per pound of coal	10.46	9.49	10.00	----
Coal per sq. ft. of grate area per hour	61.20	72.40	------	18.0
Moisture in steam, high pressure(%)	0.94	0.83	----	13.2
Moisture in steam, low pressure(%)	1.10	2.02	83.7	----
Draft in front end of smoke box (in. of water)	6.1	7.2	----	18.0
Temperature of escaping gases, deg. F	376.1	514.2	37.0	----
Drop in steam press. cylinder	9.2	4.9	----	46.9
Boiler horse power	1439	1515	----	5.2
Boiler efficiency	77.1	64.9	18.8	----
Distance of run, miles	29.5	29.7	----	----
No. of cars in train	20.5	22.5	----	9.8
Tonnage of train	1458.7	1511.6	----	3.6
Speed, miles per hour	11.0	13.1	----	19.0
Pounds of coal per 1000 ton-mile excluding delay and wt. of engine & tender	278.1	273.7	----	1.6
Indicated H.P.	1397.7	1604.3	----	14.8
Drawbar horse power	1093.7	1347.0	----	23.2
Per cent of drawbar to indicated horse power	78.2	83.9	----	7.2

9.- Southern Pacific Railway.

Comparative tests were made of a Mallet and a Consolidation, both burning Kern River oil as fuel. The results of the

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* Ry. Age Gaz. - May 19. 1911.

test in freight service between Roseville and Summit are given in the following table.

TABLE XII.

Mallet Locomotives on Southern Pacific R.R.

Cost per mile in cents.

	Mallet		Consolidation	
	Locomotive mile	100 gross ton mile	Locomotive mile	100 gross ton mile
Repair, running	5.67	.53	5.48	1.14
Fuel	47.72	4.52	26.62	5.53
Enginemen	11.95	1.13	10.96	2.28
Lubricating	.85	.07	.43	0.23
Water	2.09	.20	1.11	0.17
	68.28	6.45	44.60	9.27

The approximate relative costs of locomotive expenses as shown above are 70 for the Mallet and 100 for the Consolidation.

10.-Virginian Railway.

The Virginian Railway has employed Mallets in the mountain district between Elmore and Princeton for over 8 years. The distance is about fourteen miles, of which the last eleven and one half miles have a grade of 2.07% ,with maximum compensated curves of 12 degrees. The Virginian Railway is employing larger and heavier Mallets constantly, and now has the largest Mallet duplex engine in the world for pusher service. This Mallet has a tractive power of 115,000 pounds working compound, and could be increased to 138,000 pounds by working simple.

In comparison with the most powerful Mikado in use by the same company, the Mallet, with its tender weighs 752,000 lbs.

the Mikado, with its tender weighs 484,700 lbs. The tractive power of the Mikado is 60,800 lbs. From the figures the Mallet, with 55% more weight, has 90% greater tractive power working compound, and 127% greater tractive power working simple. The Mallet develops 100% greater drawbar pull than the Mikado, and therefore, could do the work of two Mikados at slow speed.

B.-TESTS IN ROAD SERVICE.

The use of Mallet locomotives has not been restricted to pusher service. The possibilities of the Mallet on low grade lines, while not at first realized, have been the subject of several tests on different railways in recent years. The road service tests which have been conducted are as follows.

1.-Baltimore & Ohio R.R.

On February 20, 1906, the Baltimore & Ohio R.R. began a road service test on the Connellville division of a Mallet engine, and also of two Consolidation engines hauling the same tonnage as the Mallet. The results of the tests are recorded in Table XIII .

The Mallet in this test burned 33 1/3 per cent less fuel than the two Consolidation engines, and used 32 cents worth of lubrication against 27 cents for the two Consolidation engines.

TABLE XIII*

Road Service Test on the Baltimore & Ohio R.R.

	Two E-27 Consolidation	Mallet No. 2400
Number of cars	38	35
Tons	2473	2435
Actual running time	2 hr. 45 min.	3hr. 43 min.
Coal consumed	30000 lbs.	20000 lbs.
Pounds of coal per loco. mile	698	465
Pounds of coal per car-mile	18334	13280
Pounds of coal per ton-mile	.282	.191
Water consumed	19200	15700
Water evaporated per pound of coal	8 lbs.	6.05 lbs.

2.-New York Central & Hudson River R.R.

Probably the most thorough tests of a Mallet in road service were made by the New York Central & Hudson River R.R. in 1910 on the Pennsylvania Division between Jersey Shore and Stockale Junction, a distance of 63.07 miles. In these tests great care was given to every detail in order to assure accurate results. The tests were conducted under the supervision of three experts, one each from the New York Central& Hudson River Railroad, the Pennsylvania Railroad, and the American Locomotive Company. The tests lasted two and a half months.

The results obtained showed an increse of 40 per cent in the operating capacity of a single track division without the construction of a single mile of new track, and brought about the adoption of Mallet for this division. The daily maximum haul at the present time by the Mallets in 24 hours is 1,400 cars, where formerly the traffic handled by Consolidation locomotives was

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* Ry. Age Gaz.- Sept. 8, 1911.

1000 cars daily.

Formerly, two of the Consolidations mentioned could pull a maximum train of 3,500 tons on the ruling grades at an average speed of 15 to 18 miles per hour. Under these conditions 60 Consolidation locomotives were required, of which 31 were use in road service and 29 in pusher service. With the introduction of 26 Mallet locomotives the 60 Consolidation engines were discarded. These Mallets are able to handle the entire traffic, and the pusher service has been eliminated. A Mallet locomotive unassisted now hauls a 4000-ton train over the division on grades varying from 0.14 to 0.5 per cent; average grade, 0.302%.

In the first of the two series of tests the Mallet was found to give a considerable economy in fuel consumption per unit of work, as compared with the Consolidation at various speeds.

A second series of tests was made with the same Mallet engine, except that a superheater and a 'Security' brick arch were added, and compound cylinders were substituted. This test gave far better results than the first and, consequently these improvements were rapidly incorporated in subsequent designs.

The average savings effected by the Mallet in the foregoing tests were: 35% in fuel; 54% in ton-miles per ton of coal; 80% in overtime of crews, and increase of 40% in operating capacit without extra track, besides maintaining an average speed of 12½ miles per hour. No flange lubrication was used on the drivers in the test and the drivers showed no sharp flanges after 30,000 miles of service. The tires on the drivers lasted for 50,000 miles before they required turning.

The following table shows the summary of data derived from the foregoing tests of the Mallet and Consolidation locomotive on the New York Central.

TABLE XIV*

Comparison of Performance of Mallet and Consolidation Locomotives. New York Central & Hudson River R.R.

	Approximate average speed	2-8-0 type mean bet. the performance of the 2 Consol.	2-6-6-2 type Mallet	per cent in favor of Mallet as compared with mean for the Con.
Average speed running time, miles per hour	12.5	12.75	12.9	---
	15.0	15.70	15.2	---
	17.5	-----	17.5	---
	21.0	21.4	----	---
Average drawbar pull, pounds	12.5	22726	34071	49.9
	15.0	19883	31360	56.9
	17.5	----	23424	---
	21.0	15930	----	---
Maximum starting drawbar pull pounds.		46280	66000 (working compound)	42.6
			80000 (working simple)	72.8
Machine efficiency per cent	12.5	88.85	89.21	---
	15.0	86.17	89.16	---
	17.5	---	89.16	---
	21.0	85.35	---	---
Machine friction in pounds of drawbar pull	12.5	3066.5	4468	---
	15.0	3517	4083	---
	17.5	---	4044	---
	21.0	3288.5	---	---
Dry coal per dynamometer horse power per hour, pounds	12.5	5.235	3.15	---
	15.0	5.295	3.47	---
	17.5	---	3.65	---
	21.0	5.465	---	---

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* Ry.& Loco. Eng'g-Dec. 1911 and Ry.Age Gaz.-Nov.24,1911.

Following the completion of the tests the three experts reported the following conclusion as to the advantages of the Mallet.

1.- "Economy in train operation due to larger output in ton-mile per locomotive".

2.- " Greater economy in coal per unit of power due to the larger boiler available, and especially to the use of compound cylinders and superheated steam".

3.- " Judging from the construction of the parts of this locomotive and its riding qualities with the ability to take curvature as represented an the division over which the tests were made, there would seem to be no reason to expect any undue injury to the locomotive itself when running at a speed of 30 miles per hour."

4.-" A number of the runs were made at speeds which would indicate that 30 miles per hour would not be at all detrimental to the locomotive itself."

5.- " As to injury to the track at speeds of 30 miles per hour, the weight per axle for the Mallet locomotive is very much below that which is common practice with passenger locomotives where as high as 60,000 lbs. per axle is often employed and from this standpoint, it is considered that no undue injury would be occasioned to the track suitable for Consolidation locomotives."

It is to be regretted that in spite of the many tests which have been made on the performance of Mallet locomotives, there has been such diversity of methods as to make comparisons between tests on different roads practically useless. Moreover, the lack of published data handicaps one in arriving at proper conclusions based upon the tests, so that it is hardly possible at this time to form perfectly definite conclusion. We may, however, feel reasonably sure of certain general advantages possessed by the Mallet locomotive, as shown by the tests previously cited.

These advantages are:

A.- TRAFFIC ADVANTAGES.

1.-Maximum tonnage per train.
2.- Minimum number of locomotives and crews for handling a given tonnage.
3.- Maximum tractive force in a single unit.
4.- Ability to move half the train in the event one set of machinery is disabled
5.- Low train mileage and engine mileage, therefore reducing operating expense.

B.- MECHANICAL ADVANTAGES.

1.- Distribution of weight over a maximum number of driving axles.
2.- Less slipping of driving wheels.

CHAPTER IV

ANALYSIS OF COST OF PUSHER ENGINE SERVICE.

A.- The Cost of Pusher Engine Service as Computed by Different Authorities.

The values of the cost of operating pusher engines as computed by different authors from Wellington's time up to the present have applied to the older types of locomotives only. The Conosolidation type is the one used by most writers as a basis for estimating the cost of pusher service, since the Consolidation has long been the standard pusher engine in the United States.

The cost of pusher engine service as computed by these various writers varies to some degree. This is probably due mainly to the variation in conditions on different railroads where the problem was worked out. The following table gives the results which each of the various authors obtained.

TABLE XV[1]

Cost For Each Mile of Pusher-engine Service by Various Authorities.*

1 Reference No.	2 Authority	3 Date	4 Cost per train-mile	5 Per cent affected	6 Cost per pusher eng.mile	7 Cost[2] per pusher mile
1	Wellington	1887	$1.00	38.30	$0.3830	$0.577
2	Berry	1904	1.17	33.52	0.4020	0.504
3	Webb	1909	1.35	37.80	0.5228	0.569
4	Webb	1912	1.50	45.05	0.6757	0.678
5	Ray	1910	1.436	26.83	0.3993	0.404

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1. See page 41. * In one direction only. 2. See page 41.

The values in column 7 were obtained by multiplying the values in column 5 by $1.506, the average cost per train-mile of the railways of the United States for the years 1908-1912 inclusive as appears below:

TABLE XVI*

Average Cost Per Train-mile For The Whole United States From 1908-1912 Inclusive.

Year	Average Cost per train-mile	Average for 5 years
1912	$1.59077	
1911	1.54338	
1910	1.48865	
1909	1.43370	
1908	1.47340	$1.5060

All of the authors named have followed the general method laid down by Wellington, but have used the modern classification of operation expenses of the Interstate Commerce Commission, instead of Wellington's Classification.

1.-Reference to the treatment of the subject may be had as follows:

1.-"Economic Theory of Railway Location." page602.
2.-Am.Ry. Eng'g Ass'n - Bulletin 49.
3.-"Railroad Construction." page 324,1909 edition.
4.-" Economicsof Railroad Construction." page 324,1912 ed.
5.-"Relocation of portion of the Delaware, Lackawanna & Western R.R. Main Line." 1910 Thesis-University of Illinois.

2.- On basis per train-mile of $1.50

* Compiled from I.C.C. Report 1912. Statistics of Railways in the United States.

B.-THE COST OF MALLET ENGINE SERVICE ON PUSHER GRADES.

The relative cost of operating a mile of pusher grade with Mallet locomotives is a question of some importance. In the absence of actual tests which might show such a detailed comparison, an estimate will now be made for an average case of a Mallet pusher engine assisting a Mallet road engine.

The author has followed the same general method as Wellington in estimating the effect of the Mallet locomotive upon each item of operating expense in pusher grade service. Table XVII contains a summary of the results.

Item 1 is considered as not effected.

Item 2 is taken as 150 per cent affected, due to great weight of engine and large train-load.

Item 3 is estimated 150 per cent. The enormous weight of the engine will affect the ties to a considerable degree, even though the stresses on the ties are evenly distributed by the arrangement of the wheel loadings.

Items 4, 5, and 6 are estimated at 150 per cent affected.

Item 9.-The increased weight of the engine has no corresponding increase in stresses in bridges, trestles and culverts. However, the height and lateral width of the bridge may have to be changed ,so 100 per cent is allowed for this item.

Items 13 and 14. With increased train load and fewer trains, the effect upon these items is reduced considerably, 25 per cent is allowed.

Item 19. This item has not been considered by the different authorities, but since it depends somewhat upon the size of trains, it must be taken into consideration. 50 per cent is allowed.

Items 25, 26 and 27 are each estimated as being 150% affected, taking into consideration the greater difficulty in keeping the Mallet in repair than the older types.

Item 48 is estimated at 20 per cent affected.

Item 62 is estimated at 10 per cent affected.

Item 80 is estimated at 100 per cent affected.

Item 81 is allowed 150 per cent affected.

Items 82, 83, 84 and 85 are each allowed 75 per cent affected.

Item 90 would be affected by a less number of trains running. Hence 50 per cent affected is allowed.

Items 94 and 98 are each allowed 50 per cent.

Item 103 is allowed 10 per cent.

TABLE XVII

Cost For Each Mile Of Mallet Pusher Engine Service. Using the I.C.C. Classification of Operating Expenses for the year ending June 30,1910.

Total Class I Road

	Per cent of total expenses	Per cent affected	Cost per mile per cent
I .-Maintenance of way &structures			
1.- Superintendence	0.957		
2.- Ballast	0.497	150	$0.746
3.- Ties	3.099	150	4.648
4.- Rails	0.922	150	1.383
5.- Other track material	1.134	150	1.701
6.- Roadway and track	7.531	150	11.296
7.- Removal of snow, sand & ice	0.465		
8.- Tunnels	0.064		
9.- Bridges,trestles & culverts	1.709	100	1.709
10.- Over & under grade crossings and signs	0.061		
11.- Grade crossings, fences and cattle guards	0,343		
12.- Snow & sand,fences & snowsheds	0,022		
13.- Signals & interlocking plants	0.459	25	0.115
14.- Telegraph & telephone lines	0.191	25	0.048
15.- Electric power transmission	0.021		
16.- Buildings, fixtures,grounds	1.805		
17.- Docks and wharves	0.198		
18.- Roadway tools & supplies	0.288		
19.- Injury to persons	0.106	50	0.053
20.- Stationery and printing	0.040		
21.- Other expenses	0.018		
22.- Maintaining joint tracks, yards& other facilities,Dr	0.681		
23.- Maintaining joint tracks, yards& other facilities,Cr	0.518		
Total-Maint. of W. & S.	20.093		

Continued page 45

Table XVII-Continued

	Per cent of total expenses	Per cent affected	Cost per mile per cent
II,-Maintenance of Equipment			
24.- Superintendence	0.643		
25.- Steam Locomotives-repairs	7.770	150	11.655
26.- Steam Locomotives-renewals	0.184	150	0.276
27.- Steam Locomotives- depreciation	0.659	150	0.330
28.- Electric Locomotives-repairs	0.012		
29.- Electric Locomotives-renewals	---		
30.- Electric Locomotives-depr'tion	0.001		
31.- Passenger-train cars-repairs	1.721		
32.- Passenger-train cars-renewals	0.090		
33.- Passenger-train cars-depr'tion	0.327		
34,- Freight-train cars-repairs	7.731		
35.- Freight-train cars-renewals	0.697		
36.- Freight-train cars-depr'tion	1.722		
37.- Electric eq'p't of cars-repairs	0.009		
38.- Electric eq'p't of cars-Renewal	0.002		
39.- Electric eq'p't of cars-dep't	0.003		
40.- Floating Equipment-repairs	0.052		
41.- Floating equipment-renewals	0.003		
42.- Floating equipment-dep'tion	0.021		
43.- Work equipment-repairs	0.250		
44.- Work equipment-renewals	0.042		
45.- Work equipment-depreciation	0.050		
46.- Shop machinery and tools	0.529		
47.- Power plant equipment	0.010		
48.- Injuries to persons	0.077	20	0.015
49.- Stationery and printing	0.055		
50.- Other expenses	0.047		
51.- Maintaining joint equipment at terminals --Dr	0.078		
52.- Maintaining joint equipment at terminals --Cr	0.047		
Total Maint. of Eq.	22.738		
III.- Traffic Expenses			
53.- Superintendence	0.783		
54 Outside agencies	1.099		
55.- Advertising	0.468		
56.- Traffic association	0.085		
57.- Fast freight lines	0.224		
58.- Industrial & immigration bureau	0.052		
59.- Stationery and printing	0.363		
60.- Other expenses	0.007		
Total-Traffic expenses	3.081		

Table XVII- Continued.

	Per cent of total expenses	Per cent affected	Cost per mile per cent
IV. Transportation Expenses.			
61-Superintendence	1.198		
62-Dispatching trains	0.911	10	0.091
63-Station employes	6.902		
64-Weighing & car service ass'n.	0.134		
65-Coal and ore docks	0.143		
66-Station supplies & expenses	0.578		
67-Yardmasters and their clerks	0.817		
68-Yard conductors &brakemen	2.704		
69-Yard switch & signal tender	0.218		
70-Yard supplies and expenses	0.070		
71- Yard enginemen	1.564		
72-Enginehouse expenses-yard	0.454		
73-Fuel for yard locomotives	1.587		
74-Water for yard locomotives	0.098		
75 Lubricants for yard locomotives	0.032		
76-Other supplies for yard Loco.	0.036		
77-Operatin joint yards and terminals-Dr	1.171		
78-Operating joint yard and terminals-Cr	0.727		
79-Motormen	0.027		
80-Road enginemen	6.083	100	6.083
81-Enginehouse expenses-road	1.715	150	2.572
82-Fuel for road locomotives	10.352	75	7.764
83-Water for road locomotives	0.652	75	0.489
84-Lubricant for road locomotives	0.200	75	0.150
85-Other supplies for road loco.	0.208	75	0.156
86-Operating power plants	0.041		
87-Purchased power	0.023		
88-Road Trainmen	6.400		
89-Train supplies and expenses	1.783		
90-Interlockers & block,other signal operations	0.490	100	0.490
91-Crossing flagmen & gatemen	0.354		
92-Drawbridge operation	0.050		
93-Clearing wrecks	0.252		
94-Telegraph & telephone-operation	0.326	50	0.163
95-Operating floating equipment	0.161		
96-Express service	---		
97-Stationery and printing	0.455		
98-Other expenses	0.117	50	0.058
99-Loss & damage-freight	1.220		
100-Loss & damage-baggage	0.020		
101-Damage to property	0.269		
102-Damage to stock on-rightof way	0.206		
103-Injuries to persons	1.129	10	0.113
104-Operatin joint tracks and facilities -- Dr	0.259		
105-Operating joint tracks and facilities--- Cr	0.244		
Total-Transportation Exp.	50.438		

Table XVII- Continued.

	Per cent of total expenses	Per cent affected	Cost per mile per cent
V.-General Expenses.			
106-Salaries and expenses of general officers	0.516		
107-General office supplies and expenses	0.185		
108-Salaries and expenses of clerks and attendants	1.411		
109-Law expenses	0.608		
110-Insurance	0.424		
111-Relief department expenses	0.038		
112-Pensions	0.113		
113-Stationery and printing	0.160		
114-Other expenses	0.169		
115-General adminstration joint tracks,yards,terminals-Dr	0.037		
116-General adminstration joint tracks,yards,terminals-Cr	0.011		
Total-General expenses	3.650		52.104

Recapitulation of expenses.

I- Maintenance of way and structures	20.093
II-Maintenance of equipment	22.738
III-Traffic expenses	3.081
IV -Transportation expenses	50.438
V -General expenses	3.650

Upon the basis of a train-mile cost of $1.506, the cost of pusher engine service per mile,(one way) for the Mallet is therefore, 52.104 x $1.506= $0.782.

Table XVIII has been computed in the same general manner as Table XVII, and shows the estimated excess cost per mile of a Mallet engine pulling a train without assistance,-in other words the cost as shown in the following table is the amount to be added per train-mile over and above the average train-mile cost.

Items 2,3,4,5, and 6 are each estimated to be 50 per cent affected.

Item 9 is estimated to be 10 per cent affected. The increased cost of maintenance of the bridges, trestles and culverts is small as the extra weight of engine has but slight effect.

Items 10 and 16 are both allowed 10 per cent increase over a Consolidation.

Items 18 and 21 are allowed 5 per cent each.

Items 25, 26, and 27 are each estimated to be 100 per cent affected. The repairs of a large engine are more costly proportionately than a small one. Renewal and depreciation is allowed the same percentage.

Items 34, 35, 36 and 50 are each estimated to be 5 per cent affected.

Item 80 is allowed 10 per cent affected. The wages are higher for a larger locomotive than a small one.

Item 81 is allowed 20 per cent.

Items 82 and 83 are each estimated at 25 per cent. From the tests previously enumerated a Mallet saves an average of 35 per cent in fuel and water over two Consolidations. Then, for a Mallet as compared to one Consolidation the excess cost would be 30 per cent. We will use 50 per cent.

Item 84 is given as 110 per cent. The Mallet uses slightly more lubrication than two Consolidations as shown by tests

quoted on page 34.

Item 85 is allowed 20 per cent.

TABLE XVIII

Additional Cost per Train-mile due to the Use of a Mallet Instead of a Consolidation Engine.

Item No.	Accounts	Per cent of total expenses	Per cent affected	Cost per mile per cent
	I-Maintenance of Way&Structures			
2-	Ballast	0.497	50	0.249
3-	Ties	3.099	50	1.549
4-	Rails	0.922	50	0.461
5-	Other track materials	1.134	50	0.567
6-	Roadway and track	7.531	50	3.765
9-	Bridges,trestles & culverts	1.707	10	0.171
10-	Over & under grade crossings	0.061	10	0.006
16-	Buildings, fixtures & grounds	1.805	10	0.181
18-	Roadway tools and supplies	0.288	5	0.014
21-	Other expenses	0.018	5	0.001
	Other items not affected	3.031	0	0
	II-Maintenance of Equipment.			
25-	Steam locomotives-repairs	7.770	100	7.770
26-	Steam locomotives-renewals	0.184	100	0.184
27-	Steam locomotives-depreciation	0.659	100	0.659
34-	Freight-train cars-repairs	7.731	5	0.386
35-	" " " -renewals	0.697	5	0.035
36-	" " " depreciation	1.722	5	0.086
50-	Other expenses	0.047	5	0.002
	Other items not affected	3.928	0	0
	III-Transportation expenses.			
80-	Road enginemen	6.083	10	0.608
81-	Enginehouse expenses-road	1.715	20	0.343
82-	Fuel for road locomotives	10.352	50	5.176
83-	Water for road locomotives	0.652	50	0.326
84-	Lubricants for road locomotives	0.200	110	2.200
85-	Other supplies for road loco.	0.208	20	0.042
	Other items not affected	31.928	0	0
	IV- General Expenses			
	Not affected	3.650	0	0
				24.781

The estimated excess cost per mile of a Mallet over a Consolidation, as shown in detail in Table XVIII is 24.781 per cent. Taking the cost per train-mile at $1.506, we have the excess cost per train-mile due to the use of a Mallet instead of a Consolidation engine as,

$$0.24781 \times \$1.506 = \$0.3732.$$

In estimating the cost of operating a mile of pusher grade with a Mallet locomotive as compared to operating the same grade with two Consolidation locomotives, we may use the value of $1.506 as the cost per train-mile for a train drawn by one Consolidation. For a Mallet the cost would be $1.506 plus 2 x $0.3732 which is equal to $2.2524.

Let us take a Mallet engine of the 0-8-8-0 type weighing 611,800 lbs.(engine and tender). The estimated cost of the engine at 6 cents per lb. is $36,700. Then taking the average annual mileage of the Mallet at 40,000 miles and the rate of interest at 5%, we have

$$\$36,700.00 \times .05 = \$1835 \text{ Interest per year}$$

$$\frac{1835}{40000} = \$0.046, \text{ interest on one mile run.}$$

Deducting $0.0166 interest on the Consolidation engine, we have, $0.029 as the interest to be added.

Accepting the value of 37.32 cents as the excess cost per train-mile for a Mallet over a Consolidation engine, we have the total cost per train-mile as follows:

Cost per train-mile for a Consolidation	$1.5060
Excess cost per train-mile of a Mallet over a Consolidation, 2 x $o.3732 =	0.7464
Interest on cost of a Mallet engine	0.0290
Toatl Cost per train-mile for a Mallet-------	$2.2814

For the values on the operation of a mile of pusher grade with two Consolidation engines, (one in the front and one in the back of the train) we **may** use the value which is obtained by Webb in his "Economics of Railway Construction",page 324, i.e. 45.05% x $1.506 = 67.84 cents as the cost per mile of the pusher engine. The weight of the Consolidation locomotives is taken as 248,000 pounds (engine and tender) with an approximate cost of $13,500.00.

Assuming that the Consolidation engine has an average annual mileage of 40,000 miles and the rate of interest on the cost of the engine is 5%, then the total cost per train-mile derived for the cost of the two Consolidation is taken:

Cost per train-mile for one Consolidation	$1.5060
Cost of pusher engine service per mile for one engine both ways 2x67.84¢	1.3568
Interest on the cost of one engine per mile	0.0166
Total Cost per train-mile of two Consolidations	$2.8794

Then the saving per mile per trip one way by the Mallet locomotive over the two Consolidation locomotives is

$2.8794 - $2,2814 = $0. 5980.

Now, assuming that 10 trains are used in hauling a given traffic one way per day, the saving would be,

10 x $0. 5980 = $5.98 .

The annual saving due to the use of the Mallet on a pusher grade of 8 mile-length one way is

$5.980 x 365 x 8 = $17,461.60.

This amount is the annual saving which is due to the use of one Mallet engine in place of two Consolidations per train for traffic condition given.

We may conclude from these studies that:

(1).-The cost per mile of pusher service of a Mallet engine is slightly higher than the Consolidation engine, perhaps not more than 20%.

(2).-The excess cost per train-mile of a Mallet engine, pulling a train without assistance, over a Consolidation on the same grade is 24.781% or

$$0.24781 \times \$1.506 = \$0.3732$$

(3).- The cost of operating a mile of pusher grade with a Mallet locomotive as compared to operating the same grade with two Consolidation locomotives is $2.2814 and $2.8794 respectively. The daily saving per mile per trip one way by the Mallet locomotive over the two Consolidation locomotives is $0.5980.

CHAPTER V

THE MALLET LOCOMOTIVE AS A FACTOR IN THE SELECTION OF GRADIENTS.- REDUCING COST OF CONSTRUCTION.

A.- Selection of Ruling Gradients.

In railway location there are two problems of paramount importance, viz: Probable volume of traffic and rate of ruling grade. After the route has been determined so as to develop the greatest possible traffic the question of ruling gradient is of prime importance since the ruling gradient determines the weight and length of trains, and so plays the chief part in the fixing the cost of handling the traffic. Wellington states in his "Economic Theory of Railway Location,"[1] .."that the expense of gradients arises from two causes, which are totally distinct and must be kept so to form any correct idea of their cost or proper adjustment; the one being the direct or inherent effect of all rise and fall or curvature to increase wear and tear and expenses per train mile and the other the effect of the heaviest grade or sharpest curve to limit the weight and length of train, and thus cause an additional expense. However, gradients are the one thing among the purely engineering details on which the engineer should concentrate his attention, subordinating them only to the end of reaching the sources of traffic, if even to that."

The Mallet locomotive with its great but wide range of tractive power simplifies to a considerable extent the choice of ruling gradient and pusher gradient, and is sure to be a factor

1."Economic Theory of Railway Location"-page 397.

in future railway location, and in relocation and revision of existing lines. It should no longer be necessary, when relocating a railway in order to increase its capacity and reduce operating expenses, to go to extremely heavy capital expenditure to reduce grades to a minimum of 0.2 or 0.30 per cent, since it might be much cheaper to provide locomotives of greater tractive power. The New York Central R.R. is a good example of such economy where double tracking was avoided through the use of Mallet locomotives. Then again the use of Mallet locomotives on the St. Louis & San Francisco Railway has changed the old idea of grade reduction as the "royal road" to increased operating capacity and efficiency.

The reduction of grades has been a prominent feature of American railway reconstruction work. An excellent illustration of this practice is the Delaware, Lackawanna & Western Railroad, which has spent over $24,000,000.00 in making the relocation of two sections of its main line, one known as the Hopatcong Cut-off in New Jersey and the other the Nicholson Cut-off in Pennsylvania.

The increased train-load which a Mallet locomotive is capable of hauling as compared to a Consolidation locomotive is illustrated in Table XIX. The table shows the train-load which each type of locomotive can haul on different grades. The aim has been to select the heaviest locomotive of each type. The Mikado type is inserted in the table only for purpose of comparison. The tractive effort of the modern Consolidation and the Mikado are substantially the same.

As a numerical illustration in regard to the effect of type of engine upon ruling gradient, let us assume that each engine

TABLE XIX

Maximum Working Loads For Mallet, Mikado, and Consolidation Locomotives (Behind the Tender) on any given de facto Rate of Grade. Uncomplicated by Curvature or Fluctuations of Velocity.

Rate of Grade		Total	Mallet	Mikado	Consolidation
		Resistance	(compound)	(simple)	(simple)
Per 100	Feet per mile	lbs. per net ton	28''x44" 32"stroke	29"x28"	25"x30"
			Train-load		
Level	00.00				
.20	10.56	7	13548	8101	8250
.40	21.12	11	8484	5066	5165
.60	31.68	15	6122	3650	3730
.80	42.24	19	4754	2829	2910
1.00	52.80	23	3861	2295	2360
1.10	58.08	25	3523	2092	2158
1.20	63.36	27	3023	1918	1975
1.30	68.64	29	2788	1769	1830
1.40	73.92	31	2584	1640	1697
1.50	79.20	33	2400	1525	1580
1.60	84.48	35	2246	1424	1475
1.70	89.76	37	2104	1333	1385
1.80	95.04	39	1977	1253	1305
1.90	100.32	41	1862	1180	1230
2.00	105.60	43	1758	1113	1162
2.10	110.88	45	1663	1053	1103
2.20	116.16	47	1619	997	1060
2.30	121.44	49	1497	947	995
2.40	126.72	51	1423	900	948
2.50	132.00	53	1355	857	904
2.60	137.28	55	1293	816	864
2.70	142.56	57	1234	779	824
2.80	147.84	59	1179	744	790
2.90	153.12	61	1128	712	758
3.00	158.40	63	1081	682	726
3.20	168.96	67	994	626	672
3.40	179.52	71	916	577	622
3.60	190.08	75	848	533	577
3.80	200.64	79	785	494	538
4.00	211.20	83	729	458	500

Dimensions of Engines mentioned in Table XIX.

Mallet Locomotive, Virginian Railway, 1910.

(2-8-8-2 Type)

Weight on Drivers	475,000 lbs.
Total weight of engine and tender	752,000 lbs.
Diameter of high pressure cylinders	28"
Diameter of low pressure cylinders	44"
Stroke	32"
Diameter of Driving wheels	56"
Heating surface	6,909 sq.ft.
Superheating surface	1,311 sq.ft.
Boiler pressure, per square inch	200 lbs.

$$\text{Gross T.E.} = \frac{C^2 \times S \times 1.6P}{(R+1) \times D}$$, Working compound.

Mikado Locomotive, Chesapeake & Ohio R.R., 1912.

Weight on Drivers	242,000 lbs.
Total weight of engine and tender	491,000 lbs.
Diameter of cylinder	29"
Stroke	28"
Diameter of driving wheels	56"
Heating surface	4.051 sq.ft.
Superheating surface	832 sq.ft.
Boiler pressure, per square inch	170 lbs.

Consolidation Locomotive, Western Maryland R.R., 1914.

Weight on Drivers	217,500 lbs.
Total weight of engine and tender	424,000 lbs.
Diameter of cylinder	25"
Stroke	30"
Diameter of driving wheels	52"
Heating surface	3,148 sq.ft.
Superheating surface	594 sq.ft.
Boiler pressure, per square inch	200 lbs.

$$\text{Gross T.E.} = \frac{0.85\ Pld^2}{D}$$, Working simple.

The locomotives above are the most powerful engines of their type which have been built

is required to haul a train-load of 5,000 tons net at a speed of 6 miles an hour. What will be the ruling gradient in each case?

CASE I.- Ruling Grade.

A.- Mallet Locomotive.

$$\text{Gross T.E.} = \frac{C^2 \times s \times 1.6P}{(R+1) \times D}$$

$$= \frac{44^2 \times 32 \times 1.6 \times 200}{(2.47+1) \times 56} = 102{,}031 \text{ lbs.}$$

$$\text{T.E.} = \text{Gross T.E.} - \left[\ldots .2W_d + W_t \left(2+\frac{V}{6}\right) + \frac{V^2}{6} \right]$$

T.E. = 102,031 - 5694 = 96,330 lbs.

Inherent resistance is taken as $2+\frac{V}{6} = 3$ lbs.

Let x be the required gradient up which the Mallet can haul the 5,000 tons net, we have,

$$5000 = \frac{96330-(20x \times 376)}{(3+20x)}$$

$$X = 0,755\%$$

The Mallet locomotive with a speed of 6 miles per hour can haul a train-load of 5000 tons net up a grade of 0.75%.

B.- Mikado Locomotive.

$$\text{Gross T.E.} = \frac{0.85Pld^2}{D} = \frac{0.85 \times 170 \times 28 \times 29^2}{56}$$

$$= 60{,}760 \text{ lbs.}$$

Net T.E. = 57,690 lbs.

we have, $$5000 = \frac{57690 - (20X \times 245.5)}{3+20X}$$

$$X = 0.405\%$$

C.- Consolidation Locomotive.

$$\text{Gross T.E.} = \frac{0.85 \times 200 \times 30 \times 25^2}{52} = 61,300 \text{ lbs.}$$

$$\text{Net T.E.} = 61,300 - 2,730 = 58,570 \text{ lbs.}$$

we have,

$$5000 = \frac{58570 - (20X \times 212)}{(3 + 20X)}$$

$$X = 0.419\%$$

Case II.- Let us consider another case, using the same data as in Case I, to determine the speed which each engine can maintain with a train load of 5000 tons on a 0.40 % grade. By using the boiler tractive effort formula, we have;[1]

$$T.E._b = \frac{146\ H}{S}$$

For Mallet engine Heating surface 6909 sq.ft.
Superheating surface 1311 sq.ft.
Then total heating surface, $H = 6909 + (\frac{3}{2} \times 1311) =$ 8375 sq.ft.

Grade resistance. 20x0.40 = 8.0 lbs.
Train resistance as taken by the equation

$$5000 = \frac{\frac{(146 \times 8375) - (8 \times 376)}{S}}{(2 + \frac{S}{6}) + 8}$$

$$S = 20 \text{ miles.}$$

1.-Raymond- "Railroad Engineering."page 188.

For the Consolidation engine we may use the same results as shown in Case I, 6 miles per hour, since the grade is substantially 0.40%.

With the same tonnage then, and on the same per cent of grade, the Mallet can maintain a speed of 20 miles per hour against 6 miles by the Consolidation or the Mallet can haul 8500 tons on the same grade at a speed of 6 miles per hour. Of course it would be possible to reduce the size of Mallet so as to have less tractive power and less speed.

Now, if the grades were such as to limit the train to 5000 tons over the whole division, this would then represent the maximum train. One point which we should not lose sight of, however, is the length of the 5000-ton train. Assuming that the weight per car is 50 tons and the length 40ft., we have a length of 4000 ft. for the 100 cars, while the length for an average carload of 40 tons would be 125 cars.

In many States laws have been passed requiring three brakemen on trains and specifying the minimum number of cars to which this requirement shall apply as follows: Arkansas and Washington, 25 cars or more; New York, and Pennsylvania, 30 cars or more; Arizona and Oregon, 40 cars or more; California, Neveda,and Indiana, 50 cars or more; and North Dakota, 46 or more cars.[1]

The maximum permissable length of freight trains is difficult to determine, nevertheless it is a point of a great deal of importance. Perhaps trains longer than 100 cars or 4000

1.-Bulletin 73- Bureau of Railway Economic. Washington,D.C.

feet may be operated, but there seems to be a settled opinion that trains of more than 100 cars or 125 at the most are unwieldly in practice, and are not economically operated. For this reason the writer concludes that we are not justified in adopting grades which permit greater train loads than 5000 tons to be hauled, unless for special conditions of traffic, such as coal in 90 ton cars.

To what extent are we justified in reducing grades? On page 58 it was found that on a 0.40% grade and with a train-load of 5000 tons, the Mallet chosen can travel at a speed of 20 miles per hour; and also, that it can haul the 5000 train up a 0.75% grade at a speed of 6 miles per hour without the help of an assistant engine.

Let us estimate the justifiable cost of reduction of 0.3% in 0.70% grade for the average light Consolidation engine (instead of the heavy engine just mentioned) against the use of Mallet engines which otherwise would replace the Consolidations on 0.70 per cent grade without reducing the grade.

The Consolidation engine selected and used in this estimate has the following dimensions.

Weight on driving wheels	149,530 lbs.
Total weight of engine and tender	284,430 lbs.
Total weight of engine	167,830 lbs.
Cylinders, diameter and stroke	21" x 30"
Diameter of driving wheels	56"
Boiler pressure, per square inch	200 lbs.
Heating surface	2,415 sq.ft.
Grate area	47.3 sq.ft.

$$\text{Gross T.E.} = \frac{0.85 \times 200 \times 30 \times 21^2}{56} = 40,163 \text{ lbs.}$$

Net T.E. = 38,319 lbs.

The net tractive effort on a 0.70 per cent grade is as follows:

Grade resistance is 14 lbs. per ton.
Inherent resistance is 3 lbs. per ton when velocity is taken at 6 miles per hour.

Net T.E. = 38,319 - 1991 = 36,428 lbs.

The net tonnage that this Consolidation can haul on a 0.70 per cent grade with a speed of 6 miles per hour is

$$\frac{36428}{3+14} = 2150 \text{ tons.}$$

On a 0.30 % grade we have,

$$\frac{36428}{3+6} = 4050 \text{ tons.}$$

Assume that the amount of traffic on the 120 mile division is 50,000 tons gross each way per day. This traffic requires 24 trains per day by using the Consolidation engine mentioned on page 60, for the 0.70 % ruling grade. Then on 0.30 % grade the number of trains required is 12. The number of trains saved through the reduction of grade would be 24 - 12 = 12 trains per day.

The total daily saving in train mileage by reducing the grade from 0.70% to 0.30% for the light Consolidation engines one round trip is,

120 x 12 x 2 = 2880 miles.

Using the value of the saving per train mile of 0.4163% as obtained by Webb[1] we have the annual saving due to the reduction from 0.70% to 0.30% for the use of the Consolidation engines

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1.-"Economics of Railroad Construction", Webb, page 308.

is 2880 x 365 x 1.506 x 0.4163 = $659,047.54

This amount is the net saving (excluding rise and fall) due to the change of grade for the Consolidation engine from 0.70% to 0.30%.

Now, instead of using 24 Consolidation engines to haul the given traffic on 0.70% grade, we will use Mallets of dimensions given on page 56. Each engine can pull a 5000-ton train up the o.70% grade without any assistance of helper engine with a speed of 6 miles per hour.

The added cost per train-mile for a Mallet engine over the Consolidation is $0.3732 as found in Table XVIII. The cost of a Mallet engine is taken at $36,700 as previously figured, and the Consolidation at $15,000 per engine. Then the added cost due to use of the Mallet on 0.70% grade on a 120 mile division is

10 x $0.3732 x 120 x 365 x 2 = $326,923.20

This amount is the annual additional cost of operation for 10 Mallets due to excess cost per train-mile over a Consolidation on a 120 mile division.

The excess first cost per Mallet engine over a Consolidation is $21,000, and for the 10 Mallets would be 10x$21,700 = $217,000. In adjusting the extra cost per year for the Mallet we will assume the life of a Mallet at 20 years, and at the end of that time it will go into the scrap pile. The value derived from the scrap is estimated at $50,000 for the 10 engines. Then the additional cost per year is $167,000 ÷ 20 = $8,350. Then the total added cost per year due to the use of Mallets on 0.70% grade is :

$326, 923.20 + $8,350 = $335,273.20

However, in the substitution of the Mallet for the Consolidation engine 14 trains are saved per day in each direction. Then the annual saving for the 14 Consolidation trains by using the value of 0.4163% as the added cost per train-mile for one Consolidation engine, we have,

$$14 \times 120 \times 365 \times 2 \times 1.506 \times 0.4163 = \$768,888.78$$

Then the amount saved due to the substitution of the Mallets for the Consolidations on the 0.70% grade is

$$\$768,888.78 - \$335,273.20 = \$433,615.58.$$

Then the difference between the saving due to the reduction of grade and the substitution of the Mallets for the Consolidations is

$$\$659,047.54 - \$433,615.58 = \$225,431.96.$$

Therefore, we would be justified in expending $225431.96 \div 0.05 = \$4,508,639.12$, if the interest rate is 5%, in order to reduce the grades from 0.70% to 0.30%, instead of using Mallet locomotives. Without an accurate knowledge of the topography and local conditions of each particular case, which would enable an estimate to be made of the cost of construction involved in such reduction, no specific conclusion can be made. The indications are, however, that as a general thing, the excess cost of construction involved in a change of several per cent in the ruling grade of a division would swing the balance in favor of heavier engines.

By reference to Table XIX it will be seen that the large Mallet locomotive chosen can haul approximately 6000 tons up a 0.60% grade at a speed of 6 miles per hour. We have already con-

cluded (page 60) that for mechanical reasons 6000 tons is the approximate limit of train length. It is apparent then that for freight traffic alone, the only gain (omitting rise and fall) from reducing grades below 0.60% is in the difference in cost between the operation of a Mallet locomotive and a locomotive of one of the other types, such as the Mikado or Consolidation.

The tendency in railway location during the last sixty years has been towards obtaining the lowest possible grades consistent with cost of construction. This fundamental principle has been followed strictly, owing to the lack of tractive power of the locomotives. To-day we have locomotives which are hauling train-loads that required two or three of the older and lighter types of locomotives. The question suggests itself: How does increased tractive effort affect the desirable rate of ruling grade? Mr. J.B. Berry, in connection with his studies for reducing grades on the Union Pacific Railroad in 1904, states[1] that any ruling grades below 0.40% have no particular advantages except in the saving of time. Wellington also stated that a line built of low ruling grade when higher ruling grade could be obtained with greater economy is "magnificent but not engineering, because it does not accomplish the desired end in the most economical way."[2]

It has been previously shown that a heavy Mallet can haul a 6000 ton train up a 0.60 % grade at a speed of 6 miles per hour and that this train load is considered to be about the limit

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1.-Bulletin 49, Am.Ry. Eng.Ass'n.,Page13.

2.-Economic Theory of Railway Location"-Wellington Page 672.

for practical operation owing to its great length. Granting this, then, the most economical rate of ruling grade is likely to be approximately 0.60%, except in country where lower grades, permitting the use of lighter engines, can be had at very low construction cost.

The heavy Consolidation engine previously mentioned can haul a 6000-ton train at a speed of 6 miles per hour up the following grade,

$$6000 = \frac{58570 - (20X \times 212)}{3 + 20X}$$

$$X = 0.327\%$$

Then for the light Consolidations, the ruling grade with the same tonnage and same speed is:

$$6000 = \frac{38319 - (20X \times 142)}{3 + 20X}$$

$$X = 0.166\%$$

We see that both of these grades are ~~f~~ below 0.40% grade, which was considered by Mr. Berry to be a limit of luxury in grade for ordinary topography.

For the heavy Consolidation engines the pusher grade, using a pusher engine of the same size and type would be:

$$6000 + (2 \times 212)(20X + 3) = 2 \times 58570$$

$$X = 0.775\%$$

The question of saving in construction due to the adoption of 0.60% grade over the lower grades is very important one.

To construct a low grade such as 0.30% or 0.16% grade where 0.60% would permit the same train load to be hauled would mean financial suicide to the newly incorporated line running through rugged or moderately rough country.

The range in tractive power of the Mallet locomotive offers a considerable range in the rate of ruling grade, without sacrificing any of the advantages of maximum train load. In fact where the topography is favorable to grades between 0.40% and 0.60% a lighter Mallet than the one here used could be selected, so that the 6000 ton train could be hauled at low speed, or the larger engine could be used to secure greater speed if required.

B.-SELECTION OF PUSHER GRADES.

In the selection of pusher grades, the Mallet locomotive increases the range of choice considerably. The immense tractive effort enables higher pusher gradient to be constructed, if necessary, without sacrificing the tonnage per train.

As an illustration let us take the Mallet engine described on page 56 and ascertain the rate of pusher gradient. The engine pulls a 5000 ton train up a 0.75% grade with a velocity of 6 miles per hour. With the help of an assistant engine of the same type and size, and allowing 10% loss of power due to inefficiency of both locomotives working together, we have, when working compound,

$$(376 + 5376)(20X + 3) = (2 \times 96330) - 19266$$

$$X = 1.348\%$$

The pusher grade on which two Consolidation locomotives of the size stated on page 56 can haul the load of 5,000 tons at 6 miles per hour is:

$$(5212 - 212)(20X - 3) = (2 \times 58570) - 11714$$

$$X = 0.823\%$$

The pusher grade on which a Mallet engine, assisting a heavy Consolidation engine of the size just mentioned, can haul the same train load at a speed of 6 miles per hour is

$$(5212 - 376)(20X - 3) = (58570 - 96330) - 15490$$

$$X = 1.045\%$$

The pusher grade for two light Consolidation engines as given in page 60, pulling a 5000-ton load at a speed of 6 miles per hour is

$$(5142 - 142)(20X - 3) = (2 \times 38319) - 7660$$

$$X = 0.503\%$$

CHAPTER VI

THE MALLET LOCOMOTIVE AS A FACTOR IN INCREASED TRAIN-LOADS ON EXISTING GRADES.

For slow freight train service on grades below 0.40%, granting that 6000 tons is the approximate practicable limit of one train load, we may conclude that the Consolidation and Mikado types will continue to meet the needs. The Mallet would appear to have no advantages on grades below 0.40% unless the train load could be increased to more than 6000 tons, or unless the Mallet could be utilized for fast freight service. The former contingency seems rather remote at the present time for merchandise trains, but the latter contingency may have to be resorted to ultimately as the traffic increases.

We have seen in the preceding Chapter that for grades between 0.40% and 0.70% or 0.80% the Mallet has the distinct advantage of being able to haul the maximum train load of 5000 or 6000 tons, whereas two of the other types of locomotives, such as the Mikado, would be required. Here we have then a practicable method of increasing present train loads and therefore increasing the operating capacity of thousands of miles of American railways without going to the expensive alternative of reducing grades. The importance of bringing about such increased capacity has been brought to the attention of the railway world many times by eminent railway officials, one of the leading exponents being

Mr. James J. Hill. The erroneous assupmtion has frequently been made in this connection, however, that increased capacity implied more main tracks.

It may be argued that larger train loads than 5000 or 6000 tons of merchandise are possible by increasing the size and capacity of freight cars, thereby reducing the train resistance. While such a course is possible with cars for hauling mineral products, it is exceedingly doubtful if merchandise cars can be profitably made larger than at present. The difficulty in loading the present cars to anywhere near their capacity is familiar to all, and the problem so far has baffled solution. Then there is the question of economy in loading and unloading, and excessive handling at transfer stations, which casts further doubt upon the proposal. Taken altogether, there is little need at the present time for larger box cars.

CHAPTER VII

CONCLUSIONS.

We may conclude from the foregoing studies that:

1.-Mallet locomotives make possible a higher ruling grade than has hitherto been considered feasible, without decreasing the train tonnage per locomotive.

2.- Ruling grades of less than 0.40% can hardly be operated economically with Mallet locomotives, except for fast freight trains of large tonnage.

3.- The choice of ruling grade can no longer be made without considering the alternative of adopting a higher ruling grade with Mallet locomotives.

4.- Owing to the wide range of tractive power of Mallet locomotives, there is offered a wider choice of desirable ruling grades for new railways than formerly was the case with other types of locomotives, thereby decreasing the cost of construction of new railways.

5.- The use of Mallet locomotives for pusher service offers many possibilities for reduction in construction costs, on account of the higher rate of grade which may be used, and also because of the great range of grades which may possibly be adopted without much increase in operating expense.

6.- The capacity of existing railways may be greatly increased without building additional main tracks or reducing

existing grades.

7.- There is good reason to believe that the Mallet locomotive, or a type comparable with it in size and power, is likely to become the standard road engine on roads with ruling grades upwards of 0.40%.

8.- The practicable limit of train tonnage for mixed freight traffic appears to be in the neighborhood of 5000 tons, and therefore there is little if any advantage in securing ruling grades that permit larger train loads than this to be hauled, except where lower grades can be secured at unusually small cost.

9.- In considering grade reduction the alternative of using Mallet locomotives should be carefully analysed and the relative economies studied.

10.- There is undoubtedly room for greater economies in the operation of Mallet locomotives than in most other types, due to the comparatively short time they have been in use and the incomplete knowledge of their performance.

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