ances, the failures of steam locomotive boilers and machinery, particularly those resulting in personal injury, are relatively low as compared with the work performed. It is therefore doubtful if there is any greater proportion of risk from the steam locomotive in that regard than from electrocution and other attendant dangers from high-voltage electrification.

Transportation Possibilities with Electric Locomotives*

Summary of Savings Secured by Electrification of Steam Roads—Co-operation Between Electric and Steam Locomotive Designers Urged

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The steam locomotive is a marvelous machine, representing to a wonderful degree the combination of designers' skill and years of experience. The electric locomotive, on the other hand, while a notable machine, should, in its present service, be taken as indicative only of what may be accomplished in the future. The transportation problem is about the most serious one which now confronts the American people. For a number of reasons, for only part of which the railroads are responsible, provision for the movement of railroad traffic has fallen far behind the productive capacity and needs of the country today. At the same time, the demand for traffic movement will undoubtedly be doubled in about twelve years. So the question arises, What are we going to do, and how are we going to do it?

The limit to physical expansion of railroad line and terminals has been about reached in many cases, on account of both the prohibitive cost and the inefficiency of terminals of unworkable size. A large measure of relief can still be secured by line and terminal revisions and improvements, but when the inevitable increase in the demand for traffic movement of the future is considered these expedients to secure relief are seen to be only temporary and very limited in extent.

The great need of the country is the free and expeditious movement of traffic. The way to move traffic is to *move it* and to keep it moving. The yearly average of 22 miles per day for a freight car for the whole country, with monthly averages of as low as 5 miles on some of our most congested railroads for a single month, emphasizes the fact that this is a problem that some how, some way, we must solve. The solution lies, to a large extent, in the electrification of railroads.

With the present standards of train make-up, classification and terminal handling, electrification will double the capacity of any railroad. With the better equipment we can expect in the future, together with the evolution of improved methods of operation contingent on electric power, this capacity should be doubled again, thus securing four times the present capacity.

The electric locomotive has generally, thus far, been a mere substitute for the steam locomotive, although in some cases, due to the greater power of electric locomotive, there has been a modification of the handling of traffic. Two conspicuous examples are the Norfolk & Western and the Chicago, Milwaukee & St. Paul.

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In the case of the Norfolk & Western, two electrics handle the same train as was formerly handled by three Mallet engines, but at twice the speed. In this operation, owing to the great increase in hours of road service as well, one electric locomotive is the practical equivalent of four of the Mallet engines replaced.

On the Milwaukee the notable change has been the elimination of intermediate terminals on the 440-mile electrified section between Harlowtown, Mont., and Avery, Idaho. There is at present a single intermediate engine terminal, but the latest passenger locomotives are detached from trains at this terminal for inspection and work only, which takes place about once in eight or ten trips. On regular schedule those engines make a run of 440 miles each day, being taken off for inspection at Deer Lodge after a mileage varying from 3,000 to 5,000. On occasion, when due to a schedule derangement engines have been maintained in continuous road service for thirty hours or more, for a full day of twenty-four hours records up to 766 miles in this mountain service have been established.

The advantages of electric power are its great flexibility and mobility. The difference between steam and electric locomotives is fundamental. The steam locomotive carries its own power plant, while the electric locomotive, on the other hand, is simply a transformer of power. The design of the steam locomotive is circumscribed by the necessity of tying up the rest of the machine to a steam boiler. On the other hand, the electric locomotive assembly can differ amazingly as to type, length, axle loading and driving connections. A group of small motors does not differ materially from a single large motor in efficiency. The speed and power, therefore, of an electric locomotive is limited only by conditions of track and construction, and of car equipment. It is entirely practicable to build an electric locomotive to take any train which will hold together, over any profile whatever and at any desired speed. Therefore, it should easily be practicable greatly to increase the speeds of freight trains so that they could all run at a common speed not very different from that at which the superior trains are operated.

Again, with the retirement of the lighter and weaker car equipments, a material increase in the weights of trains will be realized. Without the limitation in train speed commonly accepted as a handicap to operation of tonnage trains, who can say what the limit to train load will be with electric power? Every other industry that has been electrified has experienced a revolution in methods and service due to electrification. This should be equally true in the case of the movement of our railroad traffic.

Our present methods have been built up entirely under the necessities and limitations of the steam locomotive. This is evidenced by the existence of intermediate terminals at the ends of all the so-called engine districts, where all traffic halts. Again, the steam locomotive requires attention en route, needs supplies of water and coal, and, because of its slow movement when hauling our present tonnage trains, it is frequently sidetracked for superior trains, and thus there are more and still more halts to traffic.

Car inspection now takes place at the terminus of each engine district. If, under condition of electric operation, the engine district can be increased to 200, 400 or even 500 miles, is there any good reason why car inspection should not be eliminated at the present intermediate terminals? In fact, is not the general standard of maintenance of equipment of doubtful value on the present basis of inspection at each 100-mile interval? Cars in subway service, which is certainly full of potential hazard, are economically and reliably maintained through inspection at intervals of 1,000 to 3,000 miles. The elimination of these intermediate terminals, with the resultant necessity of keeping the trains moving on the main line, would secure an enormous increase in miles per car with a corresponding saving in equipment.

Furthermore, with the dispatch obtained in handling trains, movement could be so marshaled and scheduled that the necessity of storing goods at terminals to protect exports and local consumption would be largely eliminated, and terminals would then become in fact, as in fiction, gateways open instead of closed.

Coming now to the comparative performance of steam and electric locomotives, it is important to bear in mind that one is a generator and the other a transformer of power. The generation of power in central stations is surrounded with many refinements, and in the consumption of coal there is every opportunity for skillful handling and supervision, so that the thermal efficiency of a modern central station is relatively high and is continuously maintained at a high value. With the steam locomotive, on the other hand, the thermal efficiency is dependent not alone upon the design of the locomotive but the manner in which it is worked, its condition, which differs widely from the best, and finally by the skill in firing. The electric locomotive, on the other hand, consumes power only when in service and works at any load at its designed efficiency. The average performance, in the case of the electric, approximates the maximum in efficiency, while the steam, on average performance, will differ widely therefrom. There is further economy due to the lesser work performed, because the electric locomotive does not have to trail supplies of fuel and water, nor is there need for the hauling of coal to points of local supply, which will always be greater than hauling to electric central stations.

There are a considerable number of different designs of electric locomotives all in successful operation, and each possessing certain advantageous features. The great latitude with which electric locomotives can be designed, while fundamentally most desirable, is in itself at the present time somewhat of a handicap. This is now the subject of intensive analysis and this study is undoubtedly developing as well a better knowledge of the running characteristics of the steam locomotive.

To state the case briefly, we are all interested in the transportation problem. Electrification is bound to be the most potent factor for its relief. We should, therefore, secure the closest possible co-operation with the engineering and mechanical skill which has been so productive in the steam locomotive field.

The Electric Locomotive in Heavy Traction*

The Several Factors in Its Application Are Stated and Illustrated by References to Data from Operating and Test Records

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A COMPARISON of the modern steam and electric locomotive leads immediately to a discussion of the relative fitness of the two types of motive power to meet service conditions. At present railway practice has closely followed steam engine development, but are we not justified in looking at the transportation problem from the broader standpoint of a more powerful and adaptable type of motive power?

A locomotive is primarily a hauling machine. Its design is defined by recognized limits such as maximum degree of track curvature, coefficient of adhesion between driving wheels and rail, gross weight and dead weight per axle, tracking qualities at high speed, etc. Furthermore, the locomotive should be simple in construction, reliable and adaptable in operation and capable of being maintained in condition for a reasonable percentage of its cost.

Accepting the Mikado and Mallet as the highest developments of steam-road and helper engines for freight service, the general comparison of Table II, shown on page 872, is drawn with an entirely practicable electric locomotive that can be built without in any respect going beyond the experience embodied in locomotives now operating successfully.

The above analysis brings out the fact that to equal the hourly ton-mile performance of one electric locomotive it would require three and four engine crews respectively for the Mallet and Mikado types.

The electric locomotive has demonstrated its very great advantages in relieving congestion on single-track mountain-grade divisions. Due to the increase in number of meeting points through its higher speed, and on account of the independence of climatic conditions of the electric locomotive and other time-saving factors, it is safe to say that the daily tonnage capacity of single-track mountain-grade divisions will be increased fully 50 per cent over possible steam-engine performance by the adoption of the electric locomotive.

TABLE I—COMMONLY ACCEPTED CONSTANTS IN HEAVY TRACTION

Limiting gross weight per axle, lb	60,000
Limiting dead weight per axle, lb	18,000
Limiting coefficient adhesion running, per cent	18
Limiting coefficient adhesion starting, per cent	25
Ruling gradient, per cent	2
Maximum curvature, deg	10
Maximum rigid wheelbase, ft	18
Maximum speed on level, passenger, m.p.h	65-70
Maximum speed on level, freight, m.p.h	25-30
Maximum drawbar pull, lb	150,000

Regenerative Braking Is a Unique Element

The hazard of mountain operation is greatest on down grades, although the perfection of automatic air

*Abstract of paper read at joint meeting of A. S. M. E. and A. I. E. E. sections, New York City, Oct. 22, 1920.