ECONOMICS IN RELATION TO RAILWAY CONSTRUCTION

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The object of this paper is to consider a few aspects of railway economics and to examine some of the advantages to the community of railway development. A railway is a specialized road with easy gradients and comparatively flat curves, constructed with the object of securing economy in cost of haulage. It was recognised at an early stage of railway development that the public cart road, with its uneven contour and bad corners could not supply these needs for long-distance traffic, and, as a result of public demand and commercial requirements we have to-day, in advanced civilizations, the highly developed railway with all its complicated machinery and elaborate construction by which speed, safety and luxurious travel are attainable. The principal justification for constructing a railway is economical transport, resulting from concentration of load and mechanical power. Compared with public road transport, railways have three outstanding advantages, namely:—(a) The large tonnage that can be hauled at comparatively small cost; (b) the low cost of maintenance; (c) speed resulting from superior alignment, and which is not interrupted by the intrusion of any other form of traffic, but is only restricted by the limitations imposed by load in relation to available power, as well as by curve and gradient.
2. The development of the eastern half of Ceylon would appear to have been delayed by the lack of the cheap transport afforded by railways. It cannot be denied that considerable enterprise has been displayed and public funds expended on the construction of roads through sparsely populated districts, but the high cost of transport by motor vehicles and the slowness and limitations of the familiar bullock cart have rendered the commercial use of these roads practically negligible. Such roads, with extensions, will prove of great value as feeders to the railways of the future. It cannot be reasonably contended that the low-country dry zone, which grows, with little attention, such valuable timber as satinwood, palu, ebony, milla, ranee, etc., in abundance, is wholly devoid of fertility and usefulness, and there is no doubt that the railways now under construction in that region will render possible the exploitation of valuable timbered country which should, in time, make it unnecessary for Ceylon to obtain much timber from overseas, and even admit of an export trade being initiated. They will further render accessible, quickly and cheaply, large rice-growing areas in the neighbourhood of the great irrigation tanks, and provide opportunities for the rejuvenation of a vital industry, for Ceylon cannot be nothing if it is not agricultural, and neglect to develop its resources in that direction would be fatal to its future welfare. A further possible development resulting from these railway extensions would be that of promoting the magnificent harbour of Trincomalie from an insignificant to a busy and important port for South India, as well as for the increasing requirements of Ceylon. It is recognised that we are looking far ahead, as the realisation of this idea not only anticipates the successful completion of the present undertaking, but infers as well, the alteration of the gauge in South India to that of the main lines of Ceylon, a bridge across the straits, and the extension of the railway to Trincomalie from Madawachchi, or elsewhere. It is, however, a fair supposition, in view of the fact that South India has no large deep water har-
bours, in any way approaching the size, depth
and other natural features of Trincomalee, and
to make one would probably cost more than
the scheme outlined herein, without having
the additional advantages to this country.
The important part played by railways in the
development of a country cannot be too
strongly emphasised, and it is an established
fact that without the cheap transport provided
by railways a country’s development is seriously
hindered. The most backward portion of
Ceylon is the Eastern half of it, and it is signifi-
cant that this large area is without railways.

3. The first charge to the capital of a new
line is the preliminary survey of possible
routes and the final survey of the best one for
construction purposes. Then comes the
usually heavy expense in regard to the
acquisition of private property for the railway,
which also includes compensation for injury
done to the adjacent land which would be
divided by the railway boundaries, and ren-
dered more or less useless by the severance.
It has been estimated that the 22,000 miles of
railway in England cost Rs. 120,000 lakhs, in
Ceylon currency, of which Rs. 13,500 lakhs
went in the purchase of land, and compensa-
tion. The average cost of the railways in
England per mile, including buildings, but
not rolling stock, has been Rs. 545,445.
This, however, includes the cost of acquiring
very valuable property, and much expensive
construction through thickly populated dis-
tricts, and it better represents the magnitude of
the expenditure on the railway system,
rather than it affords a basis for local
comparisons. It is, of further interest to
note that although the vast sum men-
tioned has been spent in providing the
railways, it has taken only 1½ per cent. of that
figure, per annum, to maintain them, including
all buildings. While public roads are a per-
petual expense to the community, taking a
large percentage per annum of the capital
expenditure for maintenance, railways, other
than development lines, are revenue producers
and pay a dividend on their capital, or, when
State owned, contribute towards the income of the exchequer. A further point with regard to the employment of capital in a railway undertaking is the fact that it is very rarely fully employed, for the reason that the district it serves cannot, especially at first, provide the traffic necessary to keep the line occupied to its full capacity. It used to be the opinion that light railways should be constructed in poor agricultural districts, because, being cheaply constructed, and so employing small capital per mile on which to earn interest, they should be able to afford to carry traffic at rates below those charged by the ordinary railways. In actual practice, however, the reverse is the case, as a general rule. A well-known railway, in England, costing Rs. 6 lakhs per mile to construct but with 1,000,000 tons of traffic per annum per mile, worked at 50 per cent. of its gross receipts, earned a six per cent. dividend, though each ton contributed to capital no more than 3 cents per mile; but a light railway, costing Rs. 60,000 per mile, with 40,000 tons per mile, assuming it was possible to limit its working expenses to 50 per cent. of the gross receipts, would be obliged to charge about 12 cents a mile to pay interest on its capital at a rate of 4 per cent. only.

4. We now pass on to a brief description of the different stages in the process of constructing a railway. The preliminary survey of the country for the most satisfactory route, assuming the locality is unexplored, or only partly known, would have the portions of traverse divided into journeys of one day; the traverse stations would have their distances apart fixed by local considerations, such as bends of valleys, ascents, passes, positions of villages. The final closing of such traverse work, depends on such previously determined points laid down on trustworthy maps or charts or recorded authentically. Some such points also serve for checking intermediate places in the route; but the chief means of daily verification in all such work is direct astronomical observation aided by good chrono-
meters for giving differences of longitude. In route surveys the necessary observations for the determination of latitude, longitude and the direction of the meridian are made at least once a day; the intervening traverse work is then plotted to some convenient scale with dates, times and everything useful for record. The traverse work of an itinerary survey is dependent on compass bearings and measured or estimated distances. It should involve the smallest number of sights or changes of course. Measurements can be recorded roughly by means of the pedometer and changes of elevation by means of the aneroid. In the thick low-country jungle of Ceylon observations are only obtainable from the highest hills; from these one is able to get the general lie of the intervening country and decide upon a probable route. In such country, with the aid of his preliminary survey, the engineer would set his party to cut a survey line on a compass bearing previously decided upon for the direction of the railway, setting the straight by means of a theodolite, measuring and pegging distances along it and taking levels for purposes of grade. Starting from the sea coast, where there may be hills, it is usual to follow the coast line until it is possible to traverse the foot of the hills at a little above high sea level, or pass along a valley between the hills, to reach more regular country beyond. It may be mentioned here that it is not considered economically sound to construct a railway parallel to and close to the sea, for the reason that in such a position it can only attract traffic from one side of it, and further, it comes in direct competition with water transport, which is cheaper to conduct and, therefore, often unfavourable to the railway. Before starting work on the ground, however, it is necessary to decide upon the heaviest gradient and the sharpest curve the railway may have. This done, care has to be taken that the line follows these restrictions, and, in order to avoid heavy cost on construction and maintenance, it should be as level and as straight as possible. Keeping to the approximate direction of the proposed railway by the compass
bearing, deviations would only be necessary to avoid hills or valleys that would render a deep cutting, or high embankment essential. The angles of the deviation from the original straight would, of course, be recorded from the instrument used for the work. (It must be remembered that the work is now assumed to be in thick jungle that one cannot see through nor look over.) To avoid unfavourable physical features of the kind indicated above, cross sectioning is resorted to, by which means it is ascertained what deviation is necessary to avoid them, if they can be avoided at all. Where the depression is due to a river, or the hill is a formidable obstruction, and both cannot be avoided by a deviation, it is left to the Engineer to abandon the trial line, or to face the expense of a bridge and deep cutting, or tunnel, to meet the necessity of constructing the line in that locality. The process is continued until a length of some miles of line have been traversed, minimum curves inserted and all the changes in the surface of the ground have been recorded by levelling. The plan and longitudinal section are then plotted, and the gradients of the proposed railway are drawn on this section. An ideal section would be one on which the cuts equal the fills, thus avoiding waste of material in earthwork. The trial line that answers all requirements in view of the configuration of the country, is adopted for the railway, and finally surveyed and mapped with all necessary features to render an account of the problems to be overcome in regard to private property, etc., and with the sections, to provide data for an estimate of the earthwork, water openings, and road bridges, the sites for stations, permanent staff quarters, level-crossings, approach roads, tunnels, retaining walls and water supplies, permanent way materials and signals, for an approximate cost for the scheme. For the construction of the railway, accurate cross sections are taken at one chain intervals along the centre line, and on them when plotted is drawn the section of the earthwork to be done at those mileages. Cross sections have also to be prepared at the sites of all bridges.
and culverts for the working drawings of each to be made, and detail designs of stations and permanent quarters have to receive the Construction Engineer’s supervision. When all this data is available the quantities of materials and work to be dealt with in connection with the railway can be calculated, and a working estimate prepared. With this further information and after the acquisition of any private property, the practice in Ceylon is to engage petty contractors at piece-work rates to supply labour to proceed with the earthwork, bridges, culverts and buildings, under the supervision of the Engineer-in-charge of the work. Where the line runs through the low-country jungle, sleepers and timber for the work are obtained comparatively cheaply by local petty contractors, and where suitable brick clay is met with it is utilized for the local manufacture of standard bricks, burnt in kilns erected at the site. Lime-stone and coral are also burnt to produce lime and in most districts of Ceylon sufficient quartz gravel exists for ballasting purposes and blue gneiss stone for concrete and masonrywork. Permanent way materials, structural steelwork, signalling apparatus, and cement are imported from abroad. In England, a Railway Company wishing to promote an extension or reconstruction, has to prepare preliminary plans and estimates according to the Standing Orders of Parliament. When powers are obtained to acquire the necessary land and property, the Railway Company proceeds to obtain the detailed data above defined. This being done a form of contract and specification is carefully prepared, covering all known contingencies, and schedule of items of expenditure is drawn up. Firms of contractors with large capital and good repute are invited to tender for the whole, or part of the work, according to the contract, specification and copies of working drawings supplied; such contractors are usually in a position to finance the undertaking, supply all materials and hand the work over on completion, without receiving any assistance from the Company, whose
Engineer interprets the contract, measures the work with the Contractors' staff, and passes certificates for their monthly payments, as well as generally supervising the Contractors' operations including that of setting out the work. The contracting syndicate, as it usually is, has an Agent and a staff of Engineers to carry out the work for it. The Construction Engineer in Ceylon combines the duties of the Company's Engineer, above mentioned, with that of the Contractors' Agent at home, by preparing all the data for a new scheme and being responsible for its economical construction and successful completion. It will be seen then that all the operations in connection with launching a new railway, or any other extensive work of considerable magnitude, require the most careful attention to details of experienced Engineers; well qualified in both the theory and practice of structural work and the cheapest methods of carrying it out. In an effort to build a railway with insufficient capital it is sometimes opened for traffic, using rails and sleepers that are too light, little or no ballast, narrow cuttings and embankments, insufficient water openings with too shallow headways and many other devices to keep the cost low. To some extent such measures are justifiable, but it should always be remembered that it is very often expensive economy, and that the operating expenses are thereby increased, often to such an extent as to wipe out an easily obtainable profit. Although it is unfortunately true that the Engineer of the railway must make the best of the capital supplied him for the work, yet his recommendations should largely control the efforts to secure capital. The Engineer would be competent to recommend how much capital may profitably be spent to secure the greatest rate of nett return on the capital invested.

5. To proceed with the construction of a railway extension the base of operations would be the junction of the existing line from which the extension is to proceed. If the line has to be made to the sea coast and the distance is
considerable, a railhead may be started from the coast also, to work towards the main line junction inland. The most economical procedure to be adopted cannot be defined for all cases, as it is governed by numerous considerations. If the country to be traversed is level and devoid of all useful building materials it would be the best course to proceed with railhead only, bringing up all supplies by train. If on the other hand the country is irregular and well timbered, with prospects of yielding other useful materials, it would be in the interests of the work to spread the staff throughout the length, for the purpose of accumulating sleepers, timber, stone, sand and other materials; and to get the heavy earthwork and rock cuttings finished ready for the permanent-way to be laid, on the approach of railhead. The quantity of labour available and the prospects of providing it with the necessaries of life and keeping it in good health during the progress of the work, in an isolated and uninhabited district, are other considerations which govern the amount of work to be undertaken at once. Proceeding with railhead it is expedient to deviate the line at bridge openings and run down one side and up the other at heavier gradients than those that would be permissible for the final railway. Sleeper cribs carry the permanent-way temporarily across the river and admit of the train making progress beyond the river, while the construction of the bridge in its correct position is in hand. In this way materials for the bridge, and the work beyond, are supplied by the ballast train, thereby saving the provision of service roads for bringing material by road-vehicles at high cost.

6. Earthwork, which includes rock cutting, forms a large portion of the work of constructing a railway. In European countries the steam navvy is largely used to excavate heavy earthwork, but it has not proved an economical method locally, where manual labour, aided by light rails and tip trolleys for running off the materials to the banks, is more
satisfactory, although slower. Gravel met with in cuttings is saved for ballasting or to be washed and used in concrete work. Rock from cuttings is usually badly shattered by blasting but is useful when broken up as bottom and top ballast and for concrete work. The breaking is usually done locally by hand, but rock, met with in sufficient quantity, would be more economically dealt with by machine crushers. Every precaution is taken to keep a railway well drained, and with this object in view the permanent-way is laid on clean ballast which will not retain water. Borrow pits, from which the earth is obtained to elevate the railway above flat and low-lying country, are excavated so as to drain off the surface water to the nearest bridge or culvert. It is as necessary to protect a railway from damage by water as it is to build the abutments of bridges and culverts strong enough to resist the pressures they will have to bear, or to design the steelwork of sufficient section to withstand the strains and stresses to be encountered, for to neglect either is to endanger the safety of the public, sooner or later. When tipping embankments, 2 to 3 inches per foot is allowed for shrinkage, due to consolidation. One season's rain, together with the running of tip trollies, etc., over it, will settle a bank sufficiently to enable the sides to be trimmed, sloped and planted or turfed. The worst material will usually stand naturally at a slope of $1\frac{1}{4}$ to 1, and this is the slope to which banks are invariably trimmed. Cuttings are trimmed and dressed to anything from $\frac{1}{4}$ to 1 to 1 to 1. $\frac{1}{4}$ to 1 is often the most satisfactory, where tropical rain is likely to beat out a flatter slope: where cuttings penetrate wet clay it is necessary to adopt flat slopes for the sides, and often to insert rubble drains into the slopes and to burn a considerable layer of the clay on the upper portion, to extract the water, and thereby lessen the weight on the lower portion. Slips in cuttings are usually due to water, which must be traced and drained off before the trouble can be overcome. Bridges and culverts, as employed in railway construction, span roads, rivers, etc.
and admit of flood water passing under the railway. The span, height and materials available govern the type of structure to be adopted for any particular site, but generally speaking, where head room permits, arch spans up to 30 feet and steel girder spans above that dimension is the practice frequently adopted. Masonry and concrete structures, without steel girders that are exposed to the weather, are the more economical to maintain, as long as they are thoroughly well built in the first instance. The burnt bricks and lime of Ceylon are so inferior as to be almost useless for railway work where the structures are subject to the vibration and sudden impact of moving loads. Good stone and sand being available, the only choice is between dressed masonry and cement concrete, and owing to the speed with which the latter can be manipulated, concrete is the material most largely employed, sometimes faced with cement-sand blocks where timber for shuttering is too expensive, or otherwise unsuitable. Reinforced concrete is largely employed in European countries for railway work. It has not yet taken the place of the steel girders and trough flooring for under line bridges, but there are numerous examples of its use for over line bridges, retaining walls and other structural work. On one occasion the writer was connected with the construction of such work in London, and one of the bridges in reinforced concrete had to carry a 40-ton vehicle as an ordinary load. This structure was of two spans of 60 feet and the tender for the work had to state two prices, one for reinforced concrete, the other for steel. The tender for the reinforced concrete bridge was considerably lower than that for a steel bridge, and the former was accepted. The cheapness of reinforced concrete lies in the fact that it requires no built up steelwork, and when properly done needs no expenditure on maintenance. The shortage and cost of satisfactory supervision in Ceylon, and the difficulty of getting well seasoned timber, economically and in sufficient quantity, for shuttering, would appear to have limited the adoption of this form of construc-
tion here, to any great extent. Foundations for heavy structures have to be in perfectly solid material, and means for protecting the structure from settlement have to be adopted. To take out all the soft material in an excavation for a foundation would, in some cases, mean going down a considerable depth, which would involve heavy timbering to prevent the sides collapsing, and pumping to keep the hole free of water during construction. When suitably hard material is reached, concrete filling completes the foundation effectively, but at very high cost. Cheaper and just as good results are often obtained by:—(a) Piling, either with reinforced concrete or timber piles driven into the solid, at intervals, and capped with a grid, forming a platform upon which the masonry is erected. (b) Sheet piling of the above materials, enclosing the site of the work, thus preventing the soft foundation moving when the load comes onto it. The sheet piling is braced together at the top to prevent it spreading under the weight of the work. (c) Sinking caissons, cylinders or wells which are all made with cutting edges and excavated internally to sink by their own weights. Such work has to be carefully set out and kept vertical, otherwise the cast iron, of which cylinders and caissons are made for economy, may come under uneven pressure, and break up. On one occasion we were sinking caissons in the Thames for the widening of the Grosvenor Bridge, for two new lines of railway, and grabs were used for excavating the material. All went well for 20 feet, when it was noticed the first caisson ceased to move. Efforts were made to assist it by weight and by the use of "Jacks," which exercised pressure from the temporary staging timbers fixed above the partly built-up caisson. This was of no avail except that the caisson started to get out of vertical. It was found eventually, by diving, that the cutting edge had struck a layer of stones (septarian nodules), and that the cast-iron plates had cracked badly. The stones were removed and the caisson patched up as far as possible by placing steel packings between the sections, and in that way limiting
the cracks to the lower portion. The cutting edge ultimately reached the blue clay, 40 feet below high-water level, on which the foundation had to be made. In the other caissons steel cutting edges were provided, and with these no difficulty was experienced. 

(d) A reinforced concrete raft: A good example of this form of foundation will be found in the Colombo goods yard, where a goods shed, 750 ft. long and built on a curve, is supported on a site reclaimed from the lake, by means of a concrete-raft composed of 6:3:1 concrete reinforced with concrete lattice and second-hand rails, rejected from the permanent railway.

7. I conclude these brief notes on a few aspects of railway economics by thanking the Secretary and Members of this Association for giving me the opportunity of contributing to its discussions, which are interesting and useful, both to the Civil Engineer of mature experience and the student, on whom the working out of engineering developments of the distant future depend.