Mr. HEMANS thought the Author had enunciated a principle which no engineer of the present day would be inclined to accept, viz., that no railway should be made with long continuous inclines steeper than 1 in 40. For his own part, rather than consent to such a limit, he would be disposed to look for improvements in the locomotives. It appeared strange that the class of engine described in the Paper should have been selected for working these inclines. An engine weighing 48 tons, on eight wheels all coupled, without much arrangement for moving round sharp curves, and with a wheel base of 15 feet, or about the length of a rail, must be dangerous and unsteady when applied to that kind of work; and the effect of such an engine breaking loose, and running down an incline at the rate of 45 miles an hour, must be ruinous to the permanent way. Engines had been so improved that, with mechanical assistance, as, for instance, on the Mont Cenis railway, they could ascend inclines of 1 in 13 without any extraordinary weight on the driving wheels. In his opinion more attention should be paid to distribute the weight of the locomotive so as to obtain sufficient adhesion upon such inclines as 1 in 27 or 1 in 30, without placing such heavy weights upon any pair of wheels.

With regard to the suggestion of catch sidings at the foot of inclines, he apprehended the danger would be thereby increased. The newspapers recently contained an account of an accident on the Bhore Ghaut incline of the Great Indian Peninsula railway, where the engine, and the whole of the train ran over the end of the reversing station. This he feared might be the case at the catch sidings, unless the contour of the ground was such as to enable them to be laid out so as to bring the counteracting check of a reverse gradient to bear upon the trains; otherwise there must be enormous and costly spring buffers at the end of the sidings, to resist the impetus of the train. He thought, on the whole, it was safer to let an engine run away down a long incline, with a chance of controlling it at places where the rails were less slippery, or on any intervening levels, rather than adopt catch sidings which he believed would not lead to increased safety.

Mr. J. A. LONGRIDGE said he was responsible for the gradients adopted on this line of railway, inasmuch as long before he had any idea of being connected with its construction, he was commissioned to investigate and report whether railway communication could be made commercially successful in the Mauritius, and if so, to select the lines most deserving of attention. With the North line, which passed through the greatest sugar-producing district, there was not much difficulty: it was merely a question of the cheapest line. But with the Midland line it was altogether different; for to reach the south-east side of the island, a summit of 1,800 feet had to be surmounted, the distance in a direct line being only about 13 miles. He saw at once, from the statistics he obtained, that it was of the utmost importance to the island that the Midland line should be made, more so even than the Northern line, because it was evident that the south-eastern district would become the great future sugar-producing portion of the Mauritius. In that opinion he had been confirmed, because, from the cutting down of the forests in the centre of the island, and the consequent diminution in the quantity of water feeding the northern part, the sugar produce of that district had decreased in a remarkable degree. Some of the estates which were the finest when he first visited the island were now scarcely worth cultivating; on the other hand, estates on the south-east side of the island had become more valuable. The means of transit of the produce to the ports of shipment became, therefore, of the utmost importance; hitherto it had been carried on by small schooners with great loss and delay. He therefore recommended that the Midland line should be carried out with as little delay as possible. The first question of course that had to be decided was the extreme gradient which might be adopted; and in that he was guided a good deal by past experience. There were lines with large traffic, with gradients of 1 in 27, and he accordingly came to the conclusion, that if that gradient could be obtained he would adopt it. When the Author of the Paper laid down the principle that no gradient should be steeper than 1 in 40, it was all very well if the country was suited for that gradient: if not, such a gradient must be adopted as the country would admit of. The result of a subsequent investigation and survey, in which he was accompanied by Mr. Walmsley Stanley (M. Inst. C.E.), was to prove that the line selected in the first instance was the best. As to a gradient of 1 in 40, in that country it was simply impossible. With his subsequent experience, if he had this railway to lay out again, instead of 1 in 27 he would have recommended 1 in 12, to be worked on the centre rail system, which he was satisfied could be made both mechanically and commercially successful. It had not been fairly tested as yet on the Mont Cenis line, because disasters of all kinds had been encountered, owing to the bad quality of the engines, both in workmanship and materials. But in spite of that, he thought the working expenses of that line would compare favourably with those of the Mauritius line, either per train mile, or per-centage of receipts. Within the last month he had been able to arrive pretty accurately at the cost per train mile of the Mont Cenis railway; and with all the disasters, the short mileage, and the heavy establishment charges, it came only to 5*s.* 9*d.* per train mile.

Mr. Gregory, President, inquired what was the net load carried at that cost.

Mr. Longridge said, exclusive of the engine and carriages, the net load in goods averaged from 20 tons to 24 tons. That was not, however, a fair criterion, because the weight of the carriages must bear a fixed proportion, whether on a level or a gradient of 1 in 12. The only proof was the per-centage of working cost upon the receipts; and in the case of the Mont Cenis railway, at the present time the working expenses were 69 per cent. of the receipts. He was far from being satisfied with that; and he believed in a short time that the cost would be reduced to 4*s.* 6*d.* per train mile, and with an increased traffic, which progressed every day, that the working expenses would be brought down from 69 to 50 per cent. This was of course only an opinion, as it had not yet been done. He was surprised that the working expenses of the Mauritius line had reached so high a figure. He did not know what the actual working expenses had been for 1867—68; but in the estimates presented to the Government for 1869, he was sorry to find the working expenses put down at something like 70 per cent. of the receipts. This he could not understand, as coals cost more on the Mont Cenis line, and the rate of wages was quite as high as in the Mauritius. It was an exceedingly unsatisfactory position for this railway, which he once believed would have been a great benefit to the colony. Mr. Longridge was not aware what reasons had led to the adoption of the heavy eight-wheel coupled-engines. He did not think it a suitable class of engine for the traffic. He would have preferred two four-wheel engines,—one to be placed in front, and the other in the rear of the train. He believed that plan would have answered better, as a high speed was not required.

Mr. Bramwell wished to know what was the average gradient of the Mont Cenis line to which the train mileage given was applicable. He found the average gradient on the Mauritius line was 1 in 50 at one end and 1 in 43 at the other. He also asked what on the Mont Cenis line was the weight of the engine, compared with that of the goods and the wagons which the engine drew?

Mr. Longridge replied, that the greater portion of the Mont Cenis line, on the Italian side, was 1 in 12 and 1 in 13. On the Susa side the average gradient was 1 in 15. The engines weighed, when supplied with coke and water, about 19 tons each; and when the rails were in a favourable condition, each engine would take a train of 30 tons net load, wagons and goods included, or, including the engine, of 49 tons. At some seasons of the year the weight of the trains was limited to 18 tons or 20 tons. These figures must not be taken as of much importance, for the principle on the Mont Cenis line was that of getting the adhesion of the central rail. It was calculated to put a pressure of 30 tons on the central rail; but owing to the bad quality of the materials of the engines, that pressure was obliged to be reduced considerably, and he did not think it was more than 12 tons or 14 tons.

Consequently the loads now carried were less than would be the case if the engines were of a better description. It was not because there was not steam or power enough, but because if the necessary pressure were applied upon the rail, the engine broke. The figures he had given represented what was done under the present difficulties, not the results that would ultimately be accomplished by the central rail system. The gauge of the Mont Cenis line was 3 feet 8 inches.

Mr. Mitchell remarked that on ordinary railways, however well constructed, there were irregularities in the surface of the rails, which were aggravated by wet weather, or bad ballast. These created oscillations in the train in proportion to the extent of the irregularities. On the Mont Cenis railway it appeared to him that the centre rail must be inflexible, the horizontal wheels biting in proportion to the steepness of the gradient. He would ask whether the oscillations of the train, caused by the irregularities of the side rails, did not tend to disturb the rigidity which was necessary for the proper working of the centre rail.

Mr. Longridge replied, that springs were applied both to the central wheels and the vertical wheels, and any inequality in the road, either in the central or the ordinary rails, was compensated at once by the springs. One difficulty at first experienced was from the fact of the compression spindle, which brought the central wheels together, being rigidly connected with the frame of the engine. That threw a great strain upon it, and it broke. By giving a little play to the spindle, this was overcome. When the engine oscillated sideways as well as vertically, it was all taken up by the springs.

Mr. Huntington said, he was acquainted with every part of Mauritius, and could state that, in his opinion, the choice of gradients on the Midland line could not have been better: for in the centre of the island there was a high ridge which had to be surmounted, and it could not be avoided by going either to the right or to the left. The railway might have been constructed at a higher elevation, but he doubted if it could have been carried at a lower level; at least, not without a considerable detour, and by abandoning the chief course of the existing traffic, habitations, and cultivation, as well as the important neighbouring district of Savanne: as it was, it took a mean direction. With regard to the present position of this railway, there were several circumstances to be considered. It might now be said to be under a considerable amount of trial and suffering. It was not paying, and this was due to a variety of causes. The fares were high as compared with the European standard, fourpence per mile being the charge for first-class passengers over a distance of 24 miles, from Port Louis to Rose Belle. Of course, in regulating the charges, the cost of the line had to be taken into consideration. For nearly the whole length it was a single line, and £21,000 per mile for a single line looked a large price. The works were heavy, and the cost, under exceptional circumstances, was undoubtedly much more than had been anticipated. After leaving Curepipe to descend to Petite Rivière, there were very steep gradients, combined in several cases with sharp curves, particularly between Phœnix and Beau Bassin, and also near Port Louis. He alluded to this, because he thought the attention of engineers should be directed to the construction of locomotives and carriages of such a nature as to be more suited to the circumstances of railways like those in Mauritius than the rigid structures at present in use. The management, guards, and engine-drivers, were entitled to great praise, as the traffic had hitherto been conducted without accidents. He should also mention that at the Coromandel Station there was a heavy viaduct, the construction of which formed a large item in the cost of the line. That viaduct was, he believed, 110 feet in height, and in March, 1868, during a hurricane, the iron superstructure was blown off the piers, and carried into the river. It had since been temporarily restored by timber lattice-work, and the question had arisen whether in such a position, in a deep ravine, exposed to fearful hurricanes, the lattice system was not best suited for such a structure. He hoped the prospects of the railway would improve: it had had to contend with adverse circumstances of bad crops, and the terrible fever in 1867, so that he feared it might be some time before it would become a paying concern.

Mr. Gregory, President, observed that the attention of engineers had been much directed to the subject just referred to; and that progress had been made—notably by Mr. W. B. Adams—in adapting engines and carriages to the traversing of severe curves.

Mr. W. B. Adams supposed it would be generally admitted, that where there were sharp curves the vehicles which had to traverse them should be of a suitable construction for the purpose. To reduce the wheel and flange friction to a minimum, the wheels must move freely beneath the frame, to the right and to the left, to suit the diameters of the cones to the varying lengths of the two rails on curves, and pointing their axles truly to the centres of the curves. Thus all flange friction would be avoided. For want of this arrangement, trains were limited in length to what could be forced into the shunts, probably not two-thirds of the full load on the straight line, and the couplings were severely strained. The purpose of breaks was to absorb the momentum of a train, and bring it to a stand, either when at speed on a straight line, or against the force of gravitation on an incline. The operation of the breaks was by friction against the wheel tyres, and on the efficiency of this friction depended the result. The ordinary mode of obtaining friction was by pressing a block of soft wood against the wheel tyre, which was rapidly destroyed, and more rapidly when the fulcrum was unsteady, as in the ordinary mode of suspending the blocks from the body of the vehicle. To obtain the maximum of friction the block should be of metal, copper-lined, and covering the whole breadth of the tyre and flange with a wedging action. The fulcrum should be from the axle-box or axle direct, ensuring true action on the periphery. The breaks should be self-acting by the power of gravitation—a constant force—the normal condition being constant pressure till taken off; the direct opposite of the ordinary system, requiring manual or other force to apply the breaks, and therefore subject to neglect. The proper mechanical appliance was a long gravitation lever with the blocks at the end, acting like a steelyard beam, with a large weight at the short end pressing on the wheels, and a small weight at the long end, by which it could be lifted when it was desired to take off the pressure. If the gravitation lever multiplied twelve times, 84 lbs. at the lifting end would put a pressure of 9 cwt. on a pair of wheels, and as two levers might be used to each vehicle, a retarding force of 18 cwt. might be obtained—less the slip between the block and the wheel, which would be reduced to a minimum by the mode of application. The gravitation lever was recognized in coal and other wagons, but not properly as a travelling break. It was simply a clog applied when the wagon was at rest, in which case the suspension from the moving body did not affect it as a fulcrum. It might be taken as an axiom, that in whatever space a loaded wagon at a given speed, or on a given incline, could be stopped, with a given amount of retarding force, a whole train might be brought up in the same space with a proportionate amount of power.

Having shown how a pair of gravitation levers might be applied with a pressure of 18 cwt., or more, if required on the four wheels of a wagon, the question was how to manipulate this in a long train when running. The long end of the lever should be provided with a running sheave, through which a chain could be passed, one end to be attached to the wagon body and the other to the lifting power. In this way the weight of 84 lbs. at the lever end would be reduced to 42 lbs.; and by an intermediate snatch-block it could be again reduced to 21 lbs. A hempen cord about $\frac{1}{2}$ inch in diameter would be passed from one end of the train to the other, from the engine to the guard's van. This cord would descend in bights, or loops, to the snatch-block between every pair of wagons; the ends of the cord being affixed to winches on the engine and on the van. Thus the whole of the levers could be lifted by winding up the cord from either end. And as the cords and lifting chains could diverge from the vertical towards a horizontal line, there would be abundant play in the chains and couplings. Supposing a gravitation pressure of 18 cwt. per wagon, the lifting force required at the winch would be 42 lbs., reduced to 14 lbs., if the winch multiplied three times. Thus, in a train of forty wagons, the lifting force required would only be 560 lbs., and this equally divided between the guard and the stoker would be 280 lbs. each. An objection would doubtless be made as to complication in making up and dividing trains. To meet this, every wagon should be provided with a hand-lever at each end, which, by the application of a force of 42 lbs., would put the breaks of one wagon, or any number of wagons, out of use when needed; and the lifting-cord could also be divided into lengths by couplings. The whole of the workmanship might be of the commonest kind, needing no accurate fitting. The 'modus operandi' would be as follows: When the engine-driver was about to start, the stoker would wind up his winch and lift the whole of the breaks. When about to stop, the stoker would draw out a catch, and as the barrel revolved, the whole of the breaks would press in succession on the wheels, and the stoker could again lift them at pleasure in succession.

There were two objections to the common system of breaks; they were inefficient in power, and they were slow in operation, and this was a frequent cause of accidents. The tender-break must be on before the steam could be reversed, and the guards must be signaled at a distance. There was no apparent reason why a pair of small steam-cylinders should not be applied, to draw up wedge-breaks between the coupled driving-wheels of the engine, whether four or six, and thus retard the whole, allowing the driver instantly to reverse the steam, while at the same moment the stoker was releasing the whole of the train breaks and applying the tender or tank breaks, thus putting every wheel under powerful friction. In numerous cases the train could thus be stopped and collision avoided. Another frequent cause of accident was the breaking of a coupling, especially on steep inclines. The train perhaps separated into two parts, the engine proceeding with one half and the other half advancing slowly until the motion was reversed by gravitation. If it acquired speed backwards before the guard could apply the breaks, the application became difficult and frequently impracticable; but with the self-acting breaks just described, the severance of a coupling ensured the severance of the lifting-cords, putting all the breaks at once in action, not only on the hind portion of the train, but on that attached to the engine, thus calling the driver's attention by decreasing speed. It would act as a signal to the driver, and with very little loss of time he could recover the severed portion of the train.

Separate tenders to engines had their advocates, as a useful medium for breaks; but the separate tender had many disadvantages. With the tender and engine on one frame, a balance could be obtained which would permit the use of very large outside cylinders, enabling crank axles to be dispensed with, and perfect steadiness to be ensured in running. An engine could be arranged with six or eight driving wheels and four or six radial trailing wheels, cylinders 20 inches in diameter, and tank capacity for 2,600 gallons of water, the total wheel base of which need not exceed 30 feet, yet adapted to run round curves of 3 chains' radius without flange friction. All the wheels might have breaks, and the frame could be separated when required for lifting. Radial buffers and radiating traction might be adapted to this engine to suit similar trains on curves. The system of self-acting wagon or carriage breaks could be applied either to radial or rigid vehicles. The tank break might be brought into action by chains and a small capstan under the foot-plate, falling off by gravity; the breaks, being suspended from the axle-boxes, would follow the wheels in their radial movement.

With the constant increase of traffic, the number of trains could only be lessened by increasing their size and weight, and to do this their resistance must be reduced to a minimum, and ample self-acting break-power must be obtained. Some practical men alleged that, upon the whole, it was more profitable to take risks than to expend money in preventing them. But it would be easy to demonstrate that, when hard work had to be done, the most perfect machine was also the best paying one.

Mr. Adams submitted that this system of self-acting breaks supplied an element of safety of the greatest importance, especially in the case of steep inclines and of suburban lines where quick stopping and starting at frequent stations were needed. It might be alleged that lines of railway made quite straight, without curves, were best, and that rigid vehicles might be used on them with fixed parallel axles, and without flange friction. This was a fallacy, as there was no such thing as a straight line of rails in the sense of a pair of lathe-beds. Each pair of wheels, as constructed, formed a double cone, which theoretically compensated for differing lengths of rail pathway, by shifting the bearing on to different diameters. But to do this the wheels must have free lateral movement instead of being confined by the frames, and this movement to be true should be radial, with the axles pointing truly to the centres of the curves. Any one who watched rails when in use knew that the tread surface on which the wheels ran was not a straight line, but a series of small curves, running irregularly to the inner and the outer sides of the rails, and consequently, with the wheels working on varying diameters, inducing a sledging movement involving great friction, as evidenced by the wearing of tyres and rails. There was no remedy for this but giving the wheels free lateral play, and it had been found, in practice, that allowing the axle-boxes free end movement in the horn-plates was one mode, though not a very mechanical one, of alleviating the difficulty to a small extent.

In all countries there were natural gradients, varying according to the geological structure, and indicated by the course of streams where any existed; and these gradients mostly followed curved courses. Upon the whole it would be found, that the cost of the curved line, following the natural gradients, would be considerably less than that of the straight lines, and the working, unless in extreme cases, not more costly. It must not be forgotten that on so-called straight lines, points and crossings, shunting places, and approaches to stations and other 'turns out,' were practically all sharp curves. Of course the same speeds could not be attempted on curves as on straight lines; but there were many cases where great speeds were not required, and it was perfectly practicable to work a continuous series of **S** curves as sharp as 50-feet radius.

Mr. Harrison, Vice-President, thought this Paper involved many points of novelty, particularly when taken in conjunction with recent experience in the working of the Mont Cenis line, and the whole question was one that deserved full and deliberate discussion. He did not like the idea of an engine with eight wheels all coupled, particularly for traversing curves of small radii; as, when of ordinary construction, he did not believe such an engine was at all applicable for the purpose. He knew from experience what took place with engines with six wheels coupled on sharp curves. After being turned out of the shop and first put upon the line, the engine most probably would not go round sharp curves at all; and the only thing then to be done was to ease all the axle-boxes, and give so much play, that the engine would accommodate itself to the curve. But when an engine had eight wheels all coupled, he confessed he did not see his way to such an engine working satisfactorily.

Then came the question,—having to surmount steep gradients, what plan should be adopted? He had not visited the Mont Cenis railway, or seen the engines at work; but he did not think the short experience of the working of that line could be taken as conclusive of the final and practical success of that class of engine, if applied generally on a large scale to steep gradients. He therefore withheld his assent at present to that system being admitted to be perfectly successful; but at the same time he should be exceedingly glad to find, that the opinion he had formed—not having seen it in operation—turned out to be wrong.

Mr. Adams had stated that he could make an engine which would pass round curves of 3 chains' radius. He knew that gentleman's radial motion had been successfully applied to engines and carriages, and he had no doubt Mr. Adams was going in the right direction in designing stock for traversing sharp curves; but still he thought it would be much better, if it were possible, to avoid sharp curves, and thus remove the necessity for adopting these means of working. It was only when the curves were exceedingly sharp that it was necessary to resort to these expedients. There was no stronger argument against very sharp curves than the comparative wear of crank-axles on curves and on straight lines; and he could state from experience, that a crank-axle in an engine working on straight lines would last at least six times longer than the crank-axle of an engine working over exceedingly sharp curves.

As to Mr. Longridge's statement, that if he had to lay out the Mauritius line again he would not adopt the average gradient of 1 in 30, which he had recommended on that line, but, instead, a gradient of 1 in 12,—Mr. Harrison did not know the particular features of the country, and it was possible that by having a much steeper gradient the line might have been constructed at less cost. Still Mr. Harrison would hardly under any circumstances adopt a gradient of 1 in 12, where it was practicable to obtain a gradient of 1 in 30, as he did not think that, either as a question of economy or of facility in working, such a thing was desirable.

With regard to the commercial question, it appeared that the total cost of the Mauritius railways, although only for a single line, had been nearly £22,000 per mile, and that the working expenses amounted to 62 per cent. That would require, as nearly as possible, £3,000 per mile per annum, or £57 per mile per week, of receipts to pay 5 per cent. upon the cost. At the same time the train mileage receipts were 8*s*. 7$\frac{3}{4}$*d*., which was above the average mileage receipts of lines in England, probably half as much more: therefore £57 per mile would be practically reduced, in comparing it with English lines, to about £38 per mile per week. Now there were railways in England which had earned even more than £38 per mile per week with a single line; but he believed that was about the maximum. It was therefore not impossible that this line might pay; but the receipts, which were at present about £1,500 per mile per annum, must first be doubled. One great item in the expenses for the year 1866 was the cost of locomotive power, which had amounted to upwards of £13,000, out of a total expenditure of £25,000. On referring to the details given in the Paper, that appeared to be due, in the first place, to the high price of fuel, which cost 44*s*. 5*d*. per ton, or about five times the average that obtained in England, making the cost about 11$\frac{1}{2}$*d*. per mile; thus the total cost of locomotive power was given as nearly as possible at 2*s.* 6*d.* per mile, of which the great increase was, as before stated, in coke, and the high price of labour might perhaps account for the rest. The total cost per mile for working this line would seem to be 5*s.* 5*d.*, leaving 3*s.* $2\frac{3}{4}$*d.* net profit. That was fully equal to what any English line of railway had earned as net profit per mile. In 1867 the goods traffic amounted to 37,000 tons, which was double what it was in 1866; and as it appeared that the total quantity sent to the port of shipment from all sources was more than 100,000 tons per annum, and that the imports were as large, if the great bulk of goods could be brought upon the line, there seemed to be a fair prospect that, within a reasonable time, the line would pay a moderate dividend upon the outlay, and perhaps ultimately 5 per cent.

Mr. HAWKSHAW, Past President, said this railway had not been constructed for the purpose of earning dividends for a body of proprietors or a company; but it was executed by the Colonial Government with colonial funds. Therefore, although he agreed in the abstract in what had been said as to the commercial question, yet, under the peculiar circumstances of this railway, a more enlarged view must be taken. Thus the benefit to the island across which the line ran was an important element, and the results to the colony must not be neglected. As a national question, it had been too much the habit to disregard similar results in dealing with the railways of this country. If, for instance, this railway paid only $2\frac{1}{2}$ per cent. upon the outlay, it would probably pay double that to the colony; and on these grounds the Colonial Government might be perfectly justified in constructing it. The fact was, the Paper had been written some time ago, and therefore dealt with facts and figures gathered not long after the opening of the railway. It had been his duty to point out, to those in charge of the line, the necessity of reducing the staff considerably, and he believed this had been done. Again, the figures with regard to traffic and receipts at so early a period could scarcely, on a railway like the Mauritius, be a fair criterion of the ultimate results. The other, or what he had called the national question, though important, had rarely been touched upon in the Institution. He believed it would be easy to show, that the railways of this country had benefited the nation much more than the proprietors. If that were so in this country, he assumed it was likely to be the case in the Mauritius.

No one liked steep gradients and sharp curves, if they could be avoided. But the Midland line of the Mauritius railways was made over a rugged surface, rising up to a peak. The line as far as possible followed the undulations of the country; and a railway could not be constructed, at any justifiable cost across that ridge, except by steep gradients and sharp curves. In many cases, the gradients of a railway must correspond to the natural inclination, of the country, or else railways would not, from pecuniary reasons, be made at all.

With regard to the locomotive engines having eight wheels all coupled, they had been used with such success, that some more engines of the same kind were now being built by Messrs. R. Stephenson and Co. for the Mauritius. The weight was distributed in due proportion over the eight wheels, and no difficulty was experienced in working round the curves and up the gradients described in the Paper.

Mr. W. ATKINSON understood that the class of locomotive engine employed on the Mauritius railways would move round curves of 200 feet radius. As it appeared from the Paper that there was no curve on the line with a less radius than 950 feet, and only one instance of that, and as none of the others had a less radius than 1,600 feet, there ought to be no difficulty on this account. He had made some calculations for ascertaining the relative commercial value of the engines employed on the Mont Cenis railway, and the original engines used on the Mauritius railways. The former weighed 17 tons, with a grip on the centre rail of 20 tons, making a total of 37 tons; while the latter were about 37 tons in weight. If there was a total rise to the summit of 1,800 feet in each direction, and if it was assumed that 1 lb. of coal in a locomotive would raise 300,000 lbs. 1 foot high, then, with three trains per day in each direction, the total quantity of coal consumed per week of six days and a half, regarding Sundays as half work, to raise 20 tons, representing the excess in weight of one engine over the other, would be 4·7 tons, at, say, £2 per ton, or £9·4. This sum, distributed over the 35 miles of railway, would be 5·4 shillings per mile per week, or only 2·7 per cent. of the total working expenses, assumed at £10 per mile per week. Now supposing the cost of the central rail to be £500 per mile, the interest on that outlay, at 7 per cent., would be 13·5 shillings per mile per week, or double the cost of raising the additional 20 tons of the locomotive. Therefore, if these figures were correct, it was clear the locomotive used on the Mont Cenis railway would not be adapted for a country like the Mauritius. As he had no information of the cost of the locomotives in each case, he had not investigated that branch of the question.

Very little recorded information was to be found about the resistance of curves. He believed it was stated in the Paper what the resistance of the train was, including the resistance of the curves, but that the amount due to the curves was not given separately. He had lately to estimate the resistance of curves in Canada; and the only information he could obtain, besides Latrobe's rules, and a formula in Molesworth's pocket-book, was derived from an American Report.[1] This contained (at page 36) an account of experiments for determining the effect of gradients and curves, by Mr McCulloch, the General Superintendent of the New York and Erie railroad. The result arrived at was stated in the following extract:—

"The engine selected for the purpose was of the following proportions: Total weight, 66,050 lbs.; weight on driving-wheels, 40,050 lbs.; cylinders, 17 inches diameter; length of stroke, 24 inches; driving-wheels, 5 feet diameter; maximum pressure of steam on cylinders without slipping the wheels, 140 lbs.; or, deducting the atmospheric pressure, $125\frac{3}{10}$ lbs. effective pressure per square inch.

"The traction of the engine, that is, its power applied at the circumference of the wheels, and by which it is impelled, neglecting its friction, may be stated thus:

$$\frac{125\frac{3}{10} \times 17 \times 17 \times 24}{60} = 14{,}485 \text{ lbs.}$$

"This is the total resistance, consisting principally of the friction of the engine and tender of the cars, the gravity of the train on ascending grades, and the resistance of curves which this engine, under an effective pressure of $125\frac{3}{10}$ lbs. per square inch upon its pistons, can overcome.

"The engine and tender were moved with slightly accelerated motion, on a level, under an effective pressure of 3 lbs. Their friction, therefore, without any load attached, is

$$\frac{3 \times 17 \times 17 \times 24}{60} = 347 \text{ lbs.}$$

"It has been customary to estimate the friction of cars, with wheels of 30 inches and journals of 3 inches diameter, at about 7 lbs. per ton; or 8 lbs. per ton for wheels 33 inches and journals $3\frac{7}{8}$ inches diameter—the dimensions of those in use on this road; but the experiments made show conclusively that the friction of the loaded cars did not exceed $4\frac{1}{2}$ lbs. to 5 lbs. per ton.

"It has also been usual to estimate the additional friction of the engine, in consequence of its load, at 1 lb. per ton of its load on a level. This item will, of course, be reduced as the friction of the cars is reduced.

"After a careful examination and comparison of the loads moved upon the ruling grades and curves of various sections of the road,

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[1] *Vide* "Report of Lieut.-Col. James H. Simpson, Corps of Engineers, U.S.A., on the Union Pacific Railroad and Branches, Central Pacific Railroad of California, Northern Pacific Railroad, Wagon Roads in the Territories of Idaho, Montana, Dakota, and Nebraska, and the Washington Aqueduct. Washington, 1865." [Inst. C.E. Tracts, 8vo., vol. 170.]

it is assumed that the friction of the cars is $4\frac{1}{2}$ lbs. per ton of 2,000 lbs.; the resistance of curves $\frac{1}{2}$ lb. per ton per degree of curvature per 100 feet; and the additional friction of the engine $\frac{1}{2}$ lb. per ton of load on a level and straight line, or its equivalent.

"The weight of the engine on its drivers being 40,050 lbs., and the traction 14,485 lbs., the adhesion was, therefore, $\frac{14485}{40050} = \frac{36}{100}$, or not less than 36 per cent. of the insistent weight.

"This has heretofore been variously estimated at from $12\frac{1}{2}$ to 25 per cent.

"The tender, with its complement of wood and water, weighed 40,240 lbs."

The resistance of the curves given in this extract agreed, under certain conditions of length of train, with the results derived from the rules of Mr. Latrobe and Mr. Molesworth.

Mr. J. W. BARRY remarked that it was unfortunate the Author of the Paper should have mixed up the capital cost of the North line with that of the Midland line, as it produced confusion in the endeavour to arrive at a conclusion as to the commercial results of the Midland line. The average of nearly £22,000 per mile was arrived at by taking the whole cost of the two lines, and dividing it by the whole mileage in the island, which was 66 miles. If, then, the receipts per mile on the Midland line were considered with reference to the average cost per mile of the two lines, incorrect results would probably be obtained. The results of working the North line had not been given, but only those of the Midland line. With regard to first cost, it must be recollected that the land appeared to be exceptionally expensive for a colony, having cost the large sum of £3,000 per mile. Moreover, the expenses of raising the Government loan had been added to the cost of the railway, and a very expensive terminal station had likewise been included.

Reverting to the subject of the engines in use on this line, which had been somewhat severely criticised, he thought the weight on each pair of wheels was not excessive, and the report of the officers intrusted with the working of the railway was that the engines were satisfactory, and passed easily round the curves. If a line like this, with steep gradients of 1 in 27, or 1 in 30, had to be worked by ordinary locomotives, it was obvious that heavy engines suitable to such inclines must be employed. It had been suggested, in the course of the discussion, that instead of one heavy engine, two lighter locomotives should be employed—one in front of each train and one behind. It seemed to him, that was a fallacy. By referring to the Paper it would be found that salaries and wages amounted to 6*d*. per train mile. If two engines were used, this item of expenditure would probably be doubled. Again, the wear and tear would be for two engines instead of for one, and certainly there would be no diminution in the fuel consumed; so that instead of the working expenses being 5*s.* 5*d.* per train mile, as at present, they would amount to at least 5*s.* 11*d.*, or 6*s.* per train mile. It was true in the case of a railway with generally good gradients, and with only one or two steep inclines, a bank engine could be used economically. That, however, was not the case with the Mauritius Midland line, for it consisted almost entirely of steep gradients; and any engine which pushed a train up to the summit would have to go down again to the level of the sea to push up another. As the summit was about midway between the two termini, the proposal amounted to every train having two engines for its entire journey, thus largely increasing the locomotive expenses, which were already very heavy. It might be useful to compare the working expenses of this line with those of another colonial line—the Cape railway. That railway cost £12,000 per mile, and the receipts per mile per week were £15, against about £25 on the Mauritius line. The working expenses per train mile on the Mauritius were 5*s.* 5*d.*, or 62½ per cent. of the gross receipts; and on the Cape line, 5*s.* 3½*d.*, or 68 per cent. of the gross receipts. Looking to the larger Mauritius traffic per mile per week, and recollecting that the fixed charges on a railway, which formed a considerable proportion of the whole working expenses, did not bear much direct relation to the amount of traffic, it seemed the working expenses of the Mauritius line, with gross receipts of £25 per mile per week, were high. To compare these railways with English lines, it was necessary to recollect that in most cases of colonial lines there were no Government duties, and no rates and taxes to be paid, and no annual parliamentary expenses to be met. It would be interesting to know how the Mauritius line was situated in this respect. Taking the case of the London and Brighton railway, he found by the accounts just published for the first time in the form prescribed by the Board of Trade, that the Government duties and rates and taxes amounted to no less than 5½*d.* per train mile, while the total working cost was 3*s.* 2½*d.* per train mile. These home burdens, therefore, amounted on the Brighton railway to upwards of 14 per cent. of the gross working expenses. On the other hand, though the colonial lines were perhaps for the most part exempt from expenses corresponding to these burdens, yet the cost of conducting any enterprise by English labour in a foreign country must necessarily be great. As a rough approximation, it appeared that the working expenses of the Mauritius and the Cape railways were something like twice those of an English line, after deducting the Government duty and rates and taxes. It was right, when the public complained of high fares on the English lines, that they should be reminded that more than 14 per cent. of the gross working expenses were contributed to the public funds.

Mr. W. H. Barlow considered, that no proper comparison of receipts and expenditure could be made between a line running two or three trains each way per day, and one like the Brighton, running fifty trains per day. It was known that on all railways one large element of expenditure was of a fixed character, and the other was variable according to the traffic. It was therefore impossible to draw accurate conclusions by taking the train mileage, or per-centage, between a line which had a small amount of traffic and one which had a large amount of traffic.

Mr. Berkley observed that the special object of the Paper appeared to be to open a discussion upon the working of steep inclines on railways. Before entering on that question, he expressed a hope that some information would be supplied as to the cost of materials, labour, and fuel in the island, as also the general character of the works of the railway, and the physical conditions of the country.

The Author of the Paper had perhaps been unfortunate in the expression that, "the severity of any gradient for a long line should never exceed 1 in 40." Undoubtedly, as had been said in the course of the discussion, no such limit could be fixed. The determination of the gradient must depend upon circumstances, perhaps chiefly on the amount of the traffic and the comparative cost of construction. Those who had inspected the working of inclines, as he had done in many parts of the world, would probably conclude with him, that the Author was not wrong in saying, that if at a reasonable cost, a gradient of 1 in 40 could be obtained, it was undesirable, on account of the difficulties of working steep gradients, to adopt a steeper gradient. Of course it might be said, indeed in effect it had been said, that an increased gradient might be better, because then some other system suitable to working very steep gradients would be devised, or because the ingenuity of mechanics was such that engines would be produced to overcome the difficulties. This statement was made to excuse the adoption of an inferior gradient, and added to other conditions, it might possibly in certain cases amount to a justification. It should, however, be always remembered, that the adoption of a superior gradient required neither excuse nor justification.

The following statement would illustrate the effect of gradients in limiting the traffic which could be carried, and adding to the working charges. The power of the engines working the inclines was the same on the Mauritius, the Semmering, and the Indian Ghât inclines. The engines had cylinders 18 inches in diameter, with a length of stroke of 24 inches, and eight coupled wheels, each 4 feet in diameter. It was stated in the Paper that on gradients averaging 1 in 45, the steepest being 1 in 27 and 1 in 30, this class of engine propelled ordinarily up these inclines passenger trains of 42 tons, and goods trains of from 100 tons to 120 tons. On the Indian inclines, engines identical with these propelled passenger and goods trains, of 150 tons to 160 tons, up gradients of 1 in 37. On the Semmering, with gradients of 1 in 40, the passenger trains averaged 130 tons, and the goods trains 175 tons, and were occasionally as heavy as 200 tons. He believed the great difficulty in working steep gradients was not in ascending, but in safely descending the inclines. He was not able to give any further information with respect to the recent accident on the Bhore Ghât incline. It appeared that, with the full ordinary amount of break power on the engine and carriages, the train did overpower the breaksmen, and was precipitated over the end of the reversing station. The reversing station was a piece of level line, like the stem of the letter Y, into which the train was placed after ascending up one branch of the letter, while the engine was moved from one end of the train to the other, so as to be in the proper position to propel it up the other branch of the letter Y. It might be interesting to know the amount of break power which was desirable on inclines of this character. Some accidents had happened from the want of sufficient break power; it was therefore a matter of interest. It was stated that on the Mauritius line the train had overcome the breaksmen four times, and although no serious accident happened, unfortunate consequences might have resulted on such occasions. On the Semmering incline of 1 in 40, and on the Giovi of 1 in 36, and of 1 in 27 for a part of its length, the rule was to have one break to every two carriages in passenger trains, and to every four vehicles in goods trains. The break was applied to all the wheels of the vehicle to which it was attached. On the inclines in India the rule was to have four special break-vans and two ordinary break-vans to each train of sixteen carriages; or about one break-van to every three vehicles.

Much had been said upon commercial questions, and on the comparative cost of working the railway under consideration. He thought there was not sufficient information to enable an opinion to be formed on this subject. It seemed, however, to be agreed, that it was impossible to make any comparison between the working cost of this line and that of a line situated in England, or indeed in any country where all the circumstances were so different.

On the subject of catch sidings, his impression was that, if made in connection with the descending line, and to rise in an opposite direction, so as to absorb the momentum acquired by the train in descending the gradients on the main line, the addition of risk involved by putting in meeting points on the main line of the incline would be greater than any saving of risk which might result from the catch sidings.

The position in which the engines should be placed in the trains was a matter of importance, because accidents had arisen in some cases from placing the engine behind the train, and in other cases from the end of an ascending train breaking away from the leading part. The rule observed on the principal lines, where the gradients were steep and the curves of short radius, was with passenger trains to place the engines in front. This did not apply to goods trains, where the load was very heavy, and at starting liable to break the couplings. Then there was danger of accident from the detached portion descending the line by its own impetus, and coming in contact with a passenger train that might be following it. In such cases it was almost universally the practice to place an engine at the rear of the train—proper precautions being taken in making-up the train, by placing long vehicles, like timber-trucks, &c., near the leading engine, to prevent such vehicles being pushed off the line by the pressure from behind.

He would now state some facts relative to engines which he saw in 1864 successfully used on two or three inclines—special engines adapted to special circumstances. He did not refer to such inclines as that which passed across the Alleghany mountains, where a powerful goods engine was used. The gradient of that incline was 1 in 60, and though that might be regarded as an incline, the working of it was not varied in a material degree from the other parts of the line. On the Giovi incline there were two classes of coupled engines, some with four wheels, but the majority with six wheels, because those with four wheels were not found to be so powerful as was desired, and the weight on the wheels was destructive of the permanent way. The six-wheeled engines were worked in pairs by one driver and two firemen. Their weight was about 36 tons, and each had a tractive force of adhesion of 10,000 lbs. to 10,500 lbs., taking one-seventh of the weight for adhesion.

On the Semmering, several classes of engines were employed. One class was tried which had all the ten wheels of the engine and the tender coupled and used for the purpose of obtaining adhesion; but the complication was such, that the connection between the engine and the tender was broken, and the engine-wheels alone were coupled. This engine was not satisfactory, as although it weighed 59 tons, and the tender weighed 21 tons in addition, only the same force of adhesion, about 10,500 lbs., was obtained as with the 36-ton engines on the Giovi. This led to the construction for the Semmering incline of another class of engine, with eight wheels coupled, and weighing 47 tons, or, including the tender, 66 tons. With this a power of traction by force of adhesion was obtained of about 15,000 lbs. The engines described in the Paper were of precisely the same dimensions, and within a ton of the same weight as those used on the Indian lines, which had cylinders

18 inches in diameter, with a length of stroke of 24 inches, and eight wheels coupled, each 48 inches in diameter; and these engines weighed 49 tons in working trim. Engines of these dimensions, with an average effective pressure of steam in the cylinders of 100 lbs., would give out at the periphery of the wheels a tractive force of about 16,300 lbs. The resistances on a gradient of 1 in 37 were equal to about 70 lbs. per ton. On this gradient, therefore, these engines should propel a total load of about 230 tons, or a net load of 180 tons, being about four times their own weight. In practice, trains weighing 160 tons were propelled up this gradient. These engines had worked very satisfactorily for some years, and easily passed round curves of 20 chains' radius. They had a lateral play of 1 inch in both the leading and the trailing axle-boxes, which were arranged as follows:—The bearing-steps fitted the journals, but on the top of the axle-box there were six inclines, three on each side of the centre line. Of these the two outer inclines on each side had an angle of 1 in 8 descending from the centre of the box, while the two centre inclines had also an angle of 1 in 8, but these descended towards the centre of the box. A steel plate carried the spring piece, and had inclines on its under side which rested on the inclines on the top of the axle-box. The axle-box had a side play in the axle-guards. The effect of this arrangement was, that when the engine entered a curve, the axle-boxes slid under the steel plate which moved up the inclines, and when the engine returned to the straight line, the motion was that of sliding down the inclines to the normal or central position. This simple and excellent arrangement was introduced on the Great Indian Peninsula railway more than ten years ago by the late Mr. Cortazzi, who was then the Locomotive Superintendent. His impression was that the class of engine on the Giovi, used either in pairs or singly, and the eight-wheeled coupled engines on the Mauritius line, and the same class on the Great Indian Peninsula railway, were the best practical engines for working such inclines. Statements were often made respecting the extraordinary merits of certain engines; but he almost invariably found, that such reports proceeded from a line where the Superintendent had an interest of some kind in such engines. There was a natural bias in the human mind in favour of that which one invented, or had an interest in. From what he had seen and read on this subject, he was convinced there was not much difference between any of the classes of engines, which were simple in construction, strong, utilized all their propelling power by the force of adhesion, and did not carry too great a weight on any one pair of wheels.

Mr. R. P. Brereton thought the question of danger in working such inclines might be dismissed from consideration, inasmuch as the Mauritius railways had been opened for three or four years, and no accident had occurred, and there were only four instances of trains getting for a time beyond control. With regard to the subject of breaks, he had had an experiment made after the accident at Abergele, which justified the conclusions he previously entertained. The breaks upon the guard's van behind an ordinary goods train were put down and screwed hard and tight, and the van was then left standing upon the line while the breaking up and usual shunting of the train proceeded. He found, after two or three blows and jerks, such as were given in shunting by the backing of the engine, that the break-blocks ceased to nip the surface of the wheels, and did not prevent the wheels from turning. He had no doubt the guard might have gone away from the train in the belief that the breaks were acting perfectly throughout, whereas, after two or three blows, the nip between the break-block and the wheels had ceased. Where there was so little room for elasticity between the surface of the block and the break-screw, one or two turns were sufficient to wear and liberate the wood; and there was nothing to cause the handle or the break to follow up, as with the ordinary weighted lever break. With regard to the engines on the Mauritius railway, he could not understand how, by merely altering the lead of the slide-valve $\frac{1}{8}$ of an inch, 10 per cent. was added to the power of each engine. He should be glad to know what had led to the suggestion that produced such a result, for it was extraordinary that such an improvement could have been neglected by the eminent makers who had had from thirty to forty years' experience.

Colonel Morrison (Surveyor General of Mauritius) said that, personally, he had had nothing to do with the construction of these railways; but so far as the line of country through which they passed was concerned, he might say that, in many parts, it was one which presented considerable difficulties. Generally, the excavations had been made through hard blue basalt, volcanic rock, and a solid description of clay, called 'tufa.' The ravines were in some places deep, and liable to sudden flooding; the ground was in many localities not only thickly covered with forest, but there was an extensive undergrowth, amongst which a species of wild raspberry—the framboise de Chine—abounded, a thorny bush which occasioned great difficulty in opening out the line, and through which the Coolies could but slowly cut their way. With regard to the expense which had been incurred for the construction of the Northern and the Midland railways, it should be borne in mind that it was originally intended that there should be two independent lines, each starting from its own terminus in Port Louis, when the total cost would probably not have been more than £15,000 per mile, in lieu of that given by the Author. But it was subsequently determined to connect the two

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lines by a central, or Town, line, and an enormous portion of the actual expenditure for the railways was due to the construction of this line, which, though not much over 1 mile in length, passed through a very important part of the town. And, if the contemplated conversion of the Caudan Basin into a dock was carried out, much additional expenditure must be incurred. In framing the estimates for the cost of the railways, Colonel Morrison believed a considerable sum had been included for the importation of labour from India—something like £60,000; and large as the amount might appear, it was much to be doubted whether Mr. Longridge could have been certain of obtaining in Mauritius, at all seasons, labour sufficient to carry on the works at a rate of progress in accordance with the contract. The land in the country, it was believed, had cost a great deal more than should have been paid for it; whilst the expense incurred in purchasing the ground for the Town line, in compensation for destruction of buildings, in filling in and building in the Caudan Basin, in the useless diversion of the Pouce and Tonniers streams, in the subsequent reopening of their old channels, &c., had been very great. He recollected that, on one occasion, Mr. Longridge, in alluding to the cost of the land, had remarked that some of the planters had stated that they would make a present of their land to ensure so great a benefit to the island as the construction of railways; but when the time arrived for the fulfilment of this patriotic arrangement, their feelings of liberality had completely vanished. In framing the estimates, however, Colonel Morrison doubted whether any portion of the land required had been put down under the head of 'gratis' by Mr. Longridge.

As to the traffic of these railways, it must be borne in mind that there were many causes which operated at first, and, in fact, for some time, against large receipts. The mass of the inhabitants of Mauritius had never seen a railway, and at first a dread was entertained, by a numerous class, of the gradients and of the Grand River Viaduct on the Midland line. Many of the planters, too, were unwilling, or unable, to avail themselves of the lines at the times they were opened. The cost of transport was considered too high in most cases; whilst there were few of the planters who had not previously made their arrangements for the conveyance of the sugar crop by their own carts and mules into Port Louis, or by the native coasters where the estates lay near the coast. For many months the railways met with a determined rivalry from such transport, and for some time it was impossible that it should be otherwise. Such mules and carts as were not required for the 'entrecoupe,' or had been rendered necessary for the conveyance of the crop, could not have been all at once offered for sale, or otherwise disposed of, nor could purchasers have been readily found for the whole of the coasters. The only plan by which the traffic could have been brought to the railways would have been to have fixed the rate of transport so low as to have run the carts off the road, and rendered the use of the coasters unprofitable. And such a course would, he believed, have been good policy, even though it must have entailed temporary loss to the railways. As time passed and the traffic augmented, it was found that there were not always a sufficient number of wagons, nor sufficient locomotive power; and it was only by degrees that the planters could be brought to consider, as alterations in the rates for carriage of goods were made, the railway the cheaper means of transport. Then, too, a succession of annual droughts, disease amongst the canes, the ravages of the 'Poublanc' and the 'borer,' &c., had severely injured the sugar crop in various parts of the island; whilst in the northern and eastern districts the cultivation of considerable tracts had been abandoned. Each year produced a smaller crop than its predecessor; and one need not, therefore, be surprised, that the amount of traffic on the railways had been much less than it might have been, for the main dependence of the railways for revenue was unquestionably upon the sugar crop. If, from any cause, the crop should be much reduced, or be destroyed, the revenue of the railways would be almost gone; for the failure of the crop would not alone reduce the goods traffic, but, as every interest in the island would suffer from the deterioration or ruin of the staple produce, passenger traffic would certainly be lessened in a proportionate degree. This latter traffic, too, would, from the character of the general population, be seriously affected by any bad accident upon the railways; the effect would be much greater than would be produced from a similar accident upon any English line. The safety hitherto enjoyed certainly reflected the greatest credit upon Mr. Fisher, the original, and Mr. Mosse, the present, General Manager.

As regarded the working expenses, they must, it was feared, always amount to a high per-centage of the receipts; and, in fact, they would seldom, if ever, be less than 60 per cent. There were various circumstances which tended to make the working expenses high. Labour, skilled and unskilled, and fuel, were very expensive; carpenters, masons, and blacksmiths were paid from 3*s.* to 4*s.* 6*d.* per day; foremen, 6*d.* to 1*s.* extra; labourers from 1*s.* to 1*s.* 3*d.* a-day, exclusive generally of hutting, rations, and medical attendance; and the amount of work performed was only about equal to one-half that of an ordinary European, excluding from consideration such labour as that of railway navvies. Creole and Indian workmen required very sharp supervision, and their foremen were frequently as lazy as themselves. Engine-drivers and other Europeans were highly paid, but then it must be remembered that Mauritius was an expensive colony. The wear and tear upon such a line as the Midland must be great, and the repairs in a tropical climate were always liable to be much heavier than in a temperate climate. The main dependence, as had been already stated, of the railways for revenue was upon the sugar crop, the transport of which extended only over four months or five months of the year, after which a large portion of the rolling stock was really not required, and the outlay upon which was comparatively unremunerative during the remainder of the year. Should sickness, such as the dreadful fever of 1867, make its appearance, the price of such labour as could be obtained for current repairs would be much higher, not only from the diminished number of labourers, but from the smaller quantity of work which might each day be performed by an enfeebled class of workmen. During the crop season there was frequently a great demand for labour of all kinds amongst the planters, and the high wages, which, for a time, were paid, had sometimes the effect of creating a serious rise in the price of labour. Coal, too, was expensive, costing generally from £2 to £2. 10*s*. per ton. All these causes tended to maintain the railway expenses at a high figure, and no comparison, as it had been attempted to institute, could really be drawn between railways in Mauritius, where there was but one town of any importance, but one single article of produce was raised, and the traffic was intermittent, and English railways having a constant traffic, as regarded every description of produce throughout the year, and uniting large towns and cities, between which there was constant communication. After a few years' working, especially upon such gradients as those of the Midland line, provision would probably have to be made for the renewal of rails, sleepers, engines, &c., at no inconsiderable expense.

As far as he was capable of judging, from merely travelling over the line, the works had been carried out in a fairly substantial manner, with the exception of the station-master's quarters, booking offices, &c., at the several country stations, which were generally of a poor construction, and not well suited to a tropical climate. The accommodation, too, of the waiting-rooms, was often of an inferior description, various platforms required to be lengthened, and several of the goods sheds should have been much larger.

But there was a serious question as to the propriety of making the railways at all. For his part, he thought that their construction had never been really needed. The island had only an area of about 700 square miles. It possessed no large towns or villages (with the exception of Port Louis) between which any traffic could be established. The island laboured under the serious disadvantage of being dependent for its prosperity, he might almost say for its existence, upon one article of produce, any failure in which would seriously affect the one great source of revenue of the railways; whilst the working expenses could not be reduced to any great extent, and the heavy fixed charges for forming a sinking fund and payment of the annual interest upon the money borrowed had still to be met. Whatever facilities it might be thought existed for locomotive traffic in certain portions of the island, by reference to the map (Plate 12) it would be seen that there were large tracts which were but little, if at all, benefited by the construction of railways, whilst the main roads had still to be maintained, and many others constructed and maintained to feed the railways. No doubt a considerable improvement had been created, so far as individual comfort was concerned, in being able to travel by these railways. But when it was remembered that these railways had cost nearly a million and a half sterling, that a heavy outlay must yet be incurred, if the dock in the Caudan Basin, and other works,—not to speak of branch lines which the inhabitants of Moka and Savanne had been desirous of seeing constructed—were to be executed; and when it was considered how heavy must be the working expenses, to what great diminution of receipts the revenue might be subject in its dependence upon one single article of produce, the heavy annual provision for sinking fund and interest, it was much to be doubted whether the accommodation for goods and passenger traffic now provided was worth the outlay which had been, and must be, borne by the colony. Colonel Morrison thought the inhabitants would have done better to have remained contented with the ordinary roads, which might have been fully provided for the whole island for one-fourth of the cost of the railways, and maintained at a small expense compared with the annual expenditure upon the railways. In making these remarks, however, it was not so much for the purpose of criticising what had been done in the colony, as to suggest the consideration, how far the construction of railways was judicious in places where area, population, produce, facilities for locomotion and traffic, cost of construction and maintenance, were similar to those of Mauritius.

Mr. Fell said, the question had been raised, as to whether the central rail engine, or the ordinary locomotive, was the more profitable for working inclines of 1 in 27. He would give reasons for believing that, under certain circumstances, the central rail system was preferable. It had been implied that the gradient of 1 in 27 did not warrant the additional outlay for the central rail, and if so, it was clear, that was a case in which it ought not to be used. It had been asserted in the course of the discussion, that there were instances in which the worst gradient might be considered the best in its results, and he wished to bring forward some facts to show that it might be so, and for that purpose he would refer to an extreme case, as an example, that of the Mont Cenis line. That railway was worked with engines of a special class, which probably cost more for the same amount of tractive force than other engines, but they performed a special service which could not be performed by ordinary locomotives. Those engines could be made to work the trains over the Mont Cenis at a cost of 4*s.* 6*d.* per train mile, as the cost of working simply, to which must be added 3*s.* for interest on the capital employed, making a total of 7*s.* 6*d.* per train mile, the receipts being 12*s.* 6*d.* per train mile in that case. Comparing that with the great tunnel line, which, when it was opened, would cost 130,000,000 francs, and supposing five hundred train miles per day were run, then the cost for interest of money, exclusive of the working expenses, would be 33*s.* per train mile. The cost of working would however be reduced from 4*s.* 6*d.* to 3*s.* per train mile, because in the tunnel line there was a summit of only about 2,500 feet to overcome, as compared with 5,000 feet on the Mont Cenis summit line. Therefore he put down the 33*s.* interest on capital, and 3*s.* per train mile for working expenses, making a total cost of 36*s.* per train mile for the tunnel line as against 7*s.* 6*d.* per train mile on the summit line. That was calculated on a traffic of five hundred train miles per day on a line 50 miles in length, and to make the cost of interest and of working expenses the same in both cases, it would require an increase in the traffic of sevenfold what had been assumed, in order that the cost of carrying traffic on the tunnel line should be equal to that on the summit line. He thought it was hopeless to expect, that the traffic over any one Alpine Pass would be increased to that extent; therefore he said this was a case in which the worst gradient was obviously the best in a commercial point of view. There was also another question of importance, which should not be overlooked at a time when the public were reluctant to embark in railway investments—that was, the financial question. It was difficult to raise money for any railway now, and if the public were asked for ten millions instead of one hundred and thirty millions for any undertaking, the money was much more likely to be raised and the line to be made.

Mr. Bidder, Past-President, regretted that a subject of the utmost importance had been raised in what he considered an imperfect manner. He thought the great question of the working of railways, and the policy pursued with regard to gradients, maintenance, and renewals, was one which ought to be discussed thoroughly and entirely at the Institution.

He did not think the commercial question was raised at all in relation to the Mauritius railways. In looking at a national object they had no right to regard the per-centage of earnings: at the same time, a railway made for national purposes might no doubt be made to pay a good dividend. The results which had attended the vast railway system of this country were well known. Many companies had been brought to ruin; the greater portion received an inadequate income; and upon the whole capital embarked the average dividend was not more than 3 or 4 per cent. He had investigated what the worth of the railways was to the country, and he believed it was a tolerable approximation when he stated, that the railways made a return to the national exchequer of 15 per cent. It was true it might be said if the railways did not exist, the present amount of traffic would never have been created; but that was no answer, for it might be that the traffic was worth more than the actual amount of carriage which it produced to the railways.

The question of gradients had been referred to. For the last forty-five years he had been more or less engaged in giving evidence before Committees of Parliament on this subject. It began with the old Liverpool and Manchester line—how to get up 1 in 50. It was matter of contest with the Great Western and the London and Brighton, and again in the last instance in the proposed London, Lewes, and Brighton line. Luckily for this country, the original locomotive engines used on the London and Birmingham railway, averaged only about one-eighth of the power of those at present employed. The old engines were incapable of dealing with the ordinary traffic even at a slow speed; and he had seen, on the London and Birmingham line, three engines attached to an ordinary passenger train, under exceptional circumstances, to enable it to attempt to keep its time. The result was, gradients were measured by a few feet per mile. The prevailing gradient of the Great Western was 8 feet per mile: that of the London and North Western was 16 feet per mile; and the principal railways had been constructed with those flat gradients, which, though even when obtained at a cost beyond their worth, he believed had been fraught with the utmost advantage to the prosperity of the country.

In the case of a railway with a preponderance of passenger traffic, there might be some justification in having a gradient of 40 feet per mile; but for heavy traffic, at high speeds, it was worth while to incur additional expenditure for the sake of obtaining the best ruling gradient that the country would afford. In the year 1835 he made a survey for the railway between London and Brighton; and about the same time a learned philosopher and an able writer favoured the public with an essay upon railways, in which he laid down seventeen plain rules for the guidance of Parliament. It so happened that the line he was connected with, between London and Brighton, had gradients of 16 feet per mile, no curve less than 1½ mile radius, and only two tunnels of about 300 yards in length each. It was well supported in the City (there was no financing in those days), and eventually the Bill came before Parliament, in opposition to what was called the Direct line, which was the line ultimately made, and now passed over with so much satisfaction. This Direct line was 4 miles shorter; but it had gradients of 20 feet per mile against 16 feet per mile, and besides, there was the Croydon incline and a long tunnel. At that time, he would mention, the Committees of the House of Commons were not composed of four or five Members only, but consisted of a panel of Members selected from the counties and towns through which the line passed; and in the House of Lords the Committees were open, and every Member of the House of Lords was entitled to attend and vote. The argument on behalf of the opposition was that a line 4 miles shorter must be the more advantageous of the two. That was all very well; but a gradient of 16 feet per mile was better than one of 20 feet per mile. The bill was passed by the Commons; but when it went to the Lords the circumstances were very peculiar. The Committee was attended by fourteen peers. He should, in passing, mention that the learned writer who laid down the seventeen plain rules for the guidance of Parliament, was a supporter of the original Direct line to Brighton, which was antagonistic to that with which Mr. Bidder was connected. Singularly enough, this Direct line violated sixteen of the seventeen rules so laid down; and the consequence was, before going to the House of Lords, a subsequent edition of this book was published. After an investigation of nine or ten days before the Committee of the House of Lords, he thought a strong case had been made in favour of the line he had surveyed, and felt assured that, out of the fourteen peers, thirteen would vote for it. The only one who opposed it had a local interest. The matter came to the stage where the preamble had to be voted upon; and on that morning a well-known personage of those days made overtures to the chairman of his company; but these were not accepted, and the result was that a quarter of an hour before the vote was taken, in walked twenty-eight peers, and the preamble was declared to be lost by a vote of 29 to 13.

With regard to the great and important subject of railway policy, there was the question of closing the capital account. If that meant that a company had determined to make no more railways or branches, he could understand it; but if it meant that under no conditions whatever was the capital account to be increased, then he thought it was sheer nonsense. To take an extreme case—and he did so because it was from such examples that the tendency of things could be best seen,—suppose the traffic of the London and North Western railway to be doubled, and that the returns were six millions a year in excess of what was at present taken—that six millions of traffic would necessitate additional rolling stock, larger stations, and a probable outlay of ten millions. If the capital account was to be closed, then for three years no dividend would be paid, though such traffic would bring three millions more net revenue, and add sixty millions to the value of the undertaking. Now, considering the class of persons who held that property, such an act as that would be one of confiscation.

Then again, there was the question, under what circumstances and conditions could branch lines and extensions be usefully and beneficially undertaken? And again, the connection between the Government and the railways, on which extreme opinions existed. There were those who thought that the Government should take the railways into their own hands, as they had done the telegraphs; while others considered it better that the railways should be independent of the Government. His own feeling was that an intermediate course might be taken with advantage to all parties. The discussion which took place at this Institution on the Atmospheric Railway,[1] if it did not entirely prevent the waste of capital in the attempt to carry out that system, certainly lessened the expenditure that would otherwise have been incurred; and he believed there never was in the Institution a more useful discussion, or one which had been more practically beneficial.

Mr. Mosse's Paper had opened up another point which was introduced by Colonel Morrison, who seemed to be under the impression, that Mauritius being an island rather less than 40 miles in extent, with a rough surface, the money expended on the railways would have been more usefully laid out in perfecting the ordinary roads. Looking at the district passed through, and the sparse populations in immediate contiguity with the railways, he thought it probable that the improvement of the roads of the island might have given greater general accommodation, and have produced a better effect than a railway through one part of the island only. He readily conceived that might be the case; therefore the remarks he had made as to the advantages of railways generally must be taken as being to a great extent governed by the questions of common sense and commercial requirements.

Mr. Hawkshaw, Past-President, said the estimate for the North line was £342,530, and that for the Midland line £434,131, making a total of £776,661, and he believed those estimates had not been exceeded, in any appreciable degree, so far as the works were concerned, and that the colonists voluntarily entered upon this expenditure. The ultimate total average cost of £21,876 per mile was due to other causes. There was what was called the Town line, about $1\frac{1}{2}$ mile in length, which was projected by the

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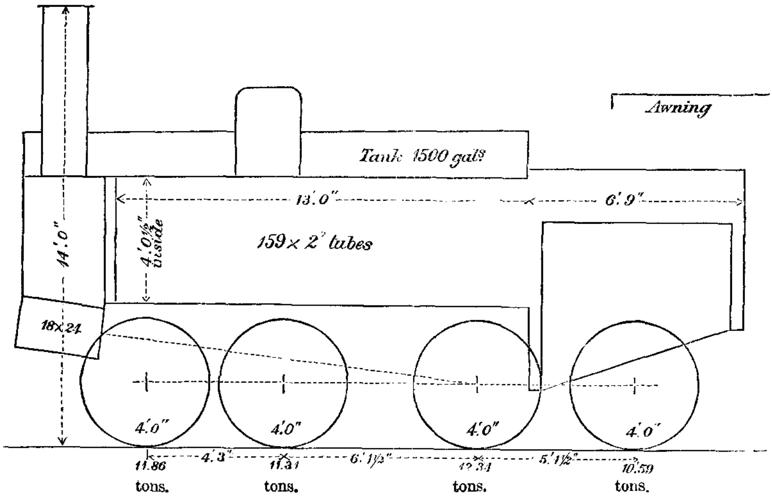
[1] *Vide* "The Peculiar Features of the Atmospheric Railway System," by G. Berkley. Minutes of Proceedings Inst. C.E., vol. iv., p. 251.

colonists themselves, and with which he had nothing to do excepting to direct the works. That line was very costly, but whether profitable or not it was a matter for the colonists themselves. Again, the land, which it might have been supposed in a colony like Mauritius would have been obtained for a small sum, had cost £195,144. The general opinion appeared to be that the price paid for the land was excessive; but it was a matter over which an engineer had no control. Then labour had to be imported to such an extent that a sum of £64,000 was put into the original contract for this contingency. If railways were made where labourers were scarce, it could not be expected that the work could be executed at a small cost. The wages of carpenters ranged from 3*s.* to 4*s.* per day; of masons from 3*s.* 6*d.* to 4*s.*; blacksmiths 3*s.* 6*d.* to 4*s.* 6*d.*; Creole fitters 3*s.* 6*d.* to 6*s.* 6*d.*; and labourers (exclusive of rations, &c.) 1*s.* 2*d.* to 1*s.* 6*d.* per day; and though these wages might not appear excessive, it must be taken in connection with the quantity of work done per man, which was small. The average amount of earthwork excavated per man per day was about $1\frac{1}{4}$ yard, and the average amount of embankment from the loose soil and stone of adjacent fields was about $1\frac{1}{2}$ yard per man; so that the labour was in fact costly. With regard to the working expenses of the line per train mile, no doubt they were heavy; but coal cost 45*s.* per ton, the wages of drivers and of skilled labour were high, and the per-centage of working expenses, as stated in the Paper, had not much bearing on the question, because that depended upon the amount of the traffic. On this line the traffic had hitherto been limited—first, because the line had only recently been opened; secondly, on account of the extraordinary mortality which occurred in the island, and which in Port Louis alone averaged as many as 207 per day—a rate sufficient to have exhausted the whole population of the island in a year or two; and, lastly, the island had been visited by one of the most terrible hurricanes ever experienced, which destroyed the crops, and a large number of buildings. These calamities, occurring almost simultaneously, were certain to diminish the traffic. The weight of the eight-wheeled coupled locomotive engines was 46 tons and not 48 tons. Fig. 1 showed the leading dimensions and form of these engines, and the way in which the weight was distributed, from which it would be seen that the weight upon any pair of wheels was in fact less than was common in this country. He certainly could not explain how it was that an alteration of $\frac{1}{8}$th of an inch in the lead of the slide-valves should have increased the power of the engines 10 per cent., and he was very doubtful about the fact. In the first place it could not be done unless the power of the engine previously was less than the amount of adhesion, which he doubted.

Fig. 1.



Heating surface:—Fire-box . . 92
Tubes . . . 1103
1195 square feet.

The Author had expressed the opinion, that for a long rise no gradient should be steeper than 1 in 40, and, on the other hand, in the course of the discussion Mr. Longridge had alluded to gradients of 1 in 12. On the subject of gradients, without attempting to enter at present into the large question which Mr. Bidder was desirous should some day be discussed, he would say he should be sorry if any precise rules were laid down either about curves or gradients. Attempts had been made to do so for the last thirty years. He remembered the time when, in the House of Commons, it was urged that trains should not be taken round curves of 40 chains' radius faster than a limited speed per hour: and he also remembered when it was said that locomotives ought not to be employed for gradients steeper than 1 in 50. All these propositions were hourly set at nought: and he trusted no attempt would now be made to lay down such laws. The fact was, all these questions were matters of experience, and it was the duty of the engineer to consider the particular circumstances and physical features of the country where railways had to be constructed, and then to devise that mode of construction which was the cheapest and the best for those circumstances and for that country. It was idle to say, if railways were wanted in a country the surface of which was like a pyramid, that the lines must not pass over its surface, more especially if the population lived there; and if the lines did pass over the surface, then the gradients must conform to the natural configuration of the country. Whatever discussion was entered into, either now or at any future time, he should strongly object to any one laying down rules which would cripple and check the inventive talent which had made railways what they were: what they might be ten or twenty years hence no one could pretend to say.

Mr. Gregory, President, said, in the face of the extreme interest of the subjects which the Paper had opened, he regretted that the discussion upon it must be closed. Under the circumstances he would not attempt to sum up the discussion; and, indeed, much that he might have said had been anticipated by those who had spoken. While interested in the discussion that had taken place on the effect of gradients on the working of railways, that subject had been by no means treated exhaustively; and he was sure all would agree with Mr. Bidder, that there was still a large field of discussion open connected with railway operations, in the Economy and Politics of Railways. It must not, however, be attempted to crowd too much into one Paper. There were some branches of those subjects which could be treated by Mr. Bidder with an ability to which few could hope to attain; and he hoped that gentleman would carry out his own suggestion, by favouring the Institution with a Paper on one or other of those important questions. Meanwhile, there were many members who must have valuable experience as to the effect of gradients upon the working of railways. He was lately looking through the Minutes of Proceedings of the Institution, and he found the information on that subject, though very useful, scattered through a large number of Papers. He thought if some member would take up the special subject of the effect of gradients on the working of railways, giving the results of experiments and facts within his own knowledge, certain rules might perhaps be established which would serve as a guide in deciding upon the gradients which, under different circumstances, would be most economical, where nature and circumstances gave an engineer a choice; but, as was justly said by Mr. Hawkshaw, very often it was necessary to take such gradients as Nature would allow, and with respect to which no choice was left.

February 9, 1869.

CHARLES HUTTON GREGORY, President, in the Chair.

The discussion upon the Paper, No. 1,202, "The Mauritius Railways—Midland Line," by Mr. Mosse, occupied the whole of the evening, to the exclusion of any other subject.