Mr. Rochussen, in elucidation of the Tables, said he had inserted a greater number of details, especially with regard to wheels, than would have been necessary if he had been dealing with rolling stock constructed in England. He had given the number of stations, showing that there was a station at about every $4\frac{3}{4}$ miles. Most of the trains on the Prussian lines were of the omnibus class, therefore the breaks were often used; and that was the special work thrown upon the tire. It was the rule of the Prussian Board of Trade, that every fifth wheel must have a break; but on the southern sections of the Cologne-Minden and Bergish Maerkish railways, where the inclines were steep, there was a break to every wheel.

He had abstracted the weight of the rails in order to explain that, on those railways, short lengths of iron permanent way had been tried experimentally, and hitherto with complete success; but as the trial had only extended over a year and a half, it would hardly be fair to bring the results before the public at present. The general features of the permanent way were, two angle irons, $6\frac{1}{2}$ inches high, by $5\frac{1}{2}$ inches wide, with a steel head between, held down by a key, which joined the two angle-irons together, and forced the steel head down. That arrangement gave a base of 12 inches; and the two flanges of the angle-iron stood at an angle of 7°. The boldest experiment was that made on the Rhenish line; and certainly the contrivance seemed rather crude: the rails were 12 inches deep, with steel tops, the base was 9 inches wide, the weight was 195 lbs. to the yard, and the rails were laid on the ballast.

Table B was intended to describe the rolling stock itself; and in that, the average results of the running wheels of the engines were given. In Germany, there was seldom any distinction made between the trailing and the leading wheels; and the running was described indiscriminately, except where the work was separated. The item was, distance run when working at a profit. If, for instance, a train from London Bridge to Croydon took a pilot-engine to go from New Cross to Norwood, that engine would get credit for a run of 5 miles; but when returning without a train, the 8 miles to London Bridge would not be credited to it except in the ultimate mileage: so that those Tables had the disadvantage of being framed in contradistinction to what was done in England; no loss was assumed at any station, but in the work done by the engines, he had expressed simply that particular work, as in Table C, col. 6. For every hour of steam at a station he had taken an average of 5 miles' work done. That was to show the effect of the frequent use of the breaks upon the tires. Every station implied the use of the breaks. In Table D, col. 5, where the total cost of the profit mile for working the engine was put down at 9·29*d*., and in Table K, col. 23, where the expense of the engine per train mile was given at 44·2*d*., the one applied to the motive power, the other to the actual cost of the train. In Table K, col. 23, the heading was expenses per engine per mile, and the amount given, viz. 44·2*d*., meant per engine-profit mile,—*i.e.* while the engine was earning money. He must remark that, in addition to column 13, Table C, where the average number of axles in a train was stated, the net load on each was an average of 73 cwt. In the results of Table B, the salaries of the whole of that department were included. The same remark applied to repairs and renewals, which comprised expenses of workshops, tools, &c. The items of oil, tallow, and cleaning were to be found in column 4 of Table D. On the Prussian railways, the cleaning was done by a separate staff; and on the Cologne-Minden it was done by contract, and cost, on an average, 1*s*. 10½*d*. per engine.

Table E referred to the repairs and renewals of engine tires. The figures in columns 2, 3, and 4 would probably appear high; the 115 per cent. did not, however, represent the ratio of those repairs, but simply the fact, that that number of tires wanted some repairs; and that was corroborated by Table M, which showed the average of years. In speaking of the wear of tires, it was necessary to state that the weight of the passenger-carriages, when empty, was about 9½ tons, which, compared with the weight of the carriages used in England, was an additional evidence in favour of those tires.

Table K was added to make the framework of the Paper rather more complete. The fares, as there indicated, were very low, and would be lower still; for, on the Belgian State system, the railway fares would be further reduced by a little more than ⅖ths; and as the Belgian system was connected indirectly with two, and directly with one of those lines, an arrangement was in course of organization by which the fares on all the lines would be reduced in some degree, if not to the same extent. The dividend of the Cologne-Minden Company was 15⅝ths per cent. By their charter they were limited to 20 per cent. The Prussian Government guaranteed 4 per cent. upon the ordinary stock; but stipulated that if more than 15 per cent. were earned, the surplus was to go as a bonus to the Government. The Cologne-Minden reserved something for every component part of the carriage, whereas, on the other lines, the reserve was a certain sum for every carriage, including all its working parts.

In Table M, the results given were those rather of calculation than of observation. There were so many different diameters of wheels, that one wheel could scarcely be compared with another, unless the wear and tear of each, as compared with its diameter, were taken into consideration, and therefore it was resolved to take the diameter of 5 feet as the standard, which reduced the wear of the tire of a 6-feet wheel running 12,000 miles till its first turning, to the wear of the same tire on a 5-feet wheel running 10,000 miles. Taking 10 tons as the load on each axle, the wear would be in the ratio of the weight upon the axles. He had accompanied this Table by another, N, which gave the average performances of all the tires, irrespective of the material, whether of puddled steel or of iron.

Of all the Tables, O might be termed the most essential, as embodying information drawn from a large number of tires. It gave every stage of turning, the distances run from one stage to another, and the thickness of steel or iron worn off, and also the distance which every $\frac{1}{10}$th of an inch of material represented. In the two latter instances, the Bochum Company's cast steel tires showed excellent results—the one, running on a steel disc wheel, being in good condition after 195,000 miles run; the other, on an iron disc, having run 288,000 miles. Column 3, in this Table, showed the effect of the use of fibrous iron in giving elasticity with steel, and that of a steel disc; and the result was 39,000 miles in the latter case, as against 42,000 miles in the former.

He wished particularly to direct attention to the favourable results shown by puddled steel and iron tires under the lighter weights. Those, with 40 cwt. on each axle, had about double the wear of tires loaded with 72 cwt. on each axle. That fact might be of greater value, from the circumstance that few English axles were required to bear more than the lighter weights given in the above Table.

As to grinding the tires, he would remark that it obviated the necessity of taking a deep bite with the tool in the lathe, by which much material was wasted. At present the workmen had to regulate his template to keep the circular form; but in an improved grinding apparatus there was a contrivance by which that plate acted on the grinding bench as a check; and when the tire was finished, the whole contrivance threw itself out of gear.

Mr. G. P. BIDDER, Past-President, was sure that all would concur in thanking the Author for having added so much to their statistical knowledge on matters connected with their practice as railway engineers. He thought great advance had been made in the character of the statistics presented to the Institution; and in venturing to suggest what he considered was necessary to perfect that information, he wished to be understood as not underrating in the slightest degree the great labours of the Author, or those of Mr. Williams, in the Paper which immediately preceded the present one.[1]

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[1] *Vide ante*, page 353

The Author had pointed out that on the Prussian railways nearly all the trains were what in England were called 'omnibus trains,' stopping at all, or at most of the stations, and were therefore subject to extra break power in arresting their progress. Now, he inferred from that statement, that the trains did not travel at the extreme speed to which the public were accustomed on most of the great lines in this country.

With regard to the wear of rolling stock and rails, he thought both were subject to three elements; there was the effect of time, of weight, and of speed. The statistics, therefore, though extremely valuable, must be and must remain imperfect till some means were adopted of eliminating each of those elements. He was prepared to subscribe to the opinion that the wear of the rails on a road was as the square of the speed of the trains, and he believed that was capable of demonstration upon the simplest principles; but there were other elements which aggravated the destruction, beyond simply the squares of the velocities.

In all those things it was necessary to recur to the commercial consideration of annual repairs and renewals. No Engineer would desire, if he could help it, to have anything else than the most perfect road that money could command; but the difficulty had always been in inducing Directors to incur the expense of providing the best materials; and after valleys had been filled up, hills cut through, and viaducts erected, that which was the crowning work of the whole—the permanent way—was often put together with the least degree of care.

With regard to permanent way, undoubtedly those three elements came into play—in the first place, the simple element of time, told upon the sleepers. Then the element of the weight of trains indirectly affected the sleepers and directly affected the rails; and lastly, hastening the destruction of both, came into play the effect of extreme speeds. Therefore in the application of creosoted sleepers and steel rails in their commercial bearing, not one of those elements should be neglected. With regard to the wear of the rails, particularly if near a station, like that of Derby, or Camden Town, and other places where the life of an ordinary rail was only from two to three years, the application of steel was of most unquestionable benefit; but with the ordinary traffic of railways, such as that on many of the branch lines, of four or five trains per day, and those running at low velocities, it was doubtful whether steel rails at £12 per ton, or £13 per ton should be applied. On an ordinary railway, and under ordinary work and circumstances, an iron rail might be calculated to last fourteen years. Then the question was, whether it was desirable to adopt the steel, or the ordinary rail? He assumed, that steel rails could be supplied at £12 per ton, while ordinary rails would cost £8 per ton. In that case there would be £4 left as the difference in the price. He assumed that a steel rail would last three times an ordinary rail. The result at the end of 14 years would be this, —The iron rail was worn out; but there were £4 in hand, which by the process of compound interest at 5 per cent. represented £8, and further, there were the old rails, which were worth £4 per ton; and thus with new rails and £4 in hand at the end of that period, a fresh commencement could be made, and that process might go on *ad infinitum.* When steel rails at £12 per ton, at the end of the 42 years had to be replaced, there would be no balance in hand, £12 being the price of the steel rails; the old rails might be disposed of at £8, but then £4 had to be found, so that there was a loss of £4 in the one case against a profit of £4 in the other case. Taking that then as the starting-point, if the traffic was such as would not prevent ordinary rails lasting 14 years, he did not see the advantage of applying steel; but for traffic which would wear them out in less than 14 years, steel rails would be the proper thing. With regard to sleepers, there was considerable discrepancy of opinion. The life of a creosoted sleeper had, on the one hand, been estimated at, he knew not how many years, while on the other hand, it had been stated that Baltic sleepers $9\frac{1}{2}$ inches by $4\frac{3}{4}$ inches could be bought at 2*s.* 4*d.* or 2*s.* 8*d.* each, and that those sleepers, unprepared, lasted for 16 years. The former part of the statement surprised him, though he did not doubt its correctness; but he must add, that the practice of using creosoted sleepers, was, if judiciously applied, one to which he was prepared to give his assent.

Mr. F. J. Bramwell said his acquaintance with the subject of railway wheel-making was of early date. He was engaged in that manufacture at a time when there was not a single line of railway into London, and when the only evidence that such a thing was about to be, was a board near where the St. Thomas's Hospital once stood, on which was written "Greenwich Railway."

The Author of the Paper was clearly in favour of disc wheels. It was indeed difficult to say why disc wheels were not received in this country. The only valid objection he had ever heard urged against them was their noise. He really believed the true source of the amount of disfavour those wheels had met with, was the absence of the supposed beauty of form which existed in the ordinary spoke-wheel. That in bygone days the beauty of form influenced the engineering mind, was undoubted; and as a proof of this he might state, that those wheels which were brought forward some twenty years ago, and which were made with semi-circular spokes, had a great run, because of their appearance; and this was maintained notwithstanding that the spokes cracked (as of necessity they must) through the rivet-holes. The disc wheel, spoken of in the Paper, appealed to the judgment of Engineers as being correct; and so long ago as the year (he believed) 1836, before the opening of the Blackwall Railway, he was engaged under the late Mr. Hague, in the manufacture of wrought-iron disc wheels. In those wheels the discs were cast into the bosses, and were in each wheel riveted to a pair of angle-irons, and the tires were riveted upon those pairs. That was much the same as the wheel shown in one of the diagrams, except that Mr. Hague's wheels had double discs instead of single ones. He never heard any objection made to those wheels, except as to their ugliness: but that was fatal; and on this ground they were a commercial failure.

So much for disc wheels in former years in England. It was well known that in America, for the large passenger-cars on eight wheels, cast-iron wheels were used as a rule—the tires being of cast iron as well as the other parts; and the disc form for those wheels was almost universal. Corrugation was given to the discs, not so much with a view to obtaining elasticity when the wheel was at work, as to prevent risk in the contraction of the casting.

Of late years the wooden disc wheels had been somewhat extensively used in England, and he believed in every case they had given great satisfaction. He must again be allowed to express his approval of the disc form, as from its use there was uniformity of support given to the tire, and, therefore, great probability of the tire being worn equally, instead of wearing into a succession of hollows, which frequently occurred when the support was given by spokes; and when once that uneven mode of wearing was set up, the destruction of the wheel was rapid, and brought with it a corresponding amount of destruction to the rails. Another advantage of the disc form was the prevention of the cloud of dust that was given off at the level of the boss of a wheel having spokes, when a train was suddenly brought to rest at a station. That dust must have an injurious effect in cutting out the journals and brasses, as it was flying about at the very time the axle-boxes were being opened to receive grease. He thought that, on the ground of uniform support to the tire, and on that of freedom from dust, the disc form of wheel was commendable.

From the ability displayed in the Paper, he had but little doubt that the grinding apparatus to which allusion had been made would be found to be well designed for its purpose: but although that particular implement might be novel, the grinding of tires, *per se*, was not a new thing. In 1840, he was engaged in the manufacture of wheels which had steel tires. That was a tire compounded of steel and iron; the steel being laid upon the iron in the pile, so that, when the tire was rolled, it was formed with a face of steel and a back of iron. In cases where those tires were put upon wooden wheels, it was necessary to quench them. That, of course, hardened the wheel surface so that it could not be turned. As a remedy, the tires had been made with a very thin skin of iron above the steel, the object being to protect the latter metal from the water, so as to leave it in a condition capable of being turned after quenching; but the plan had not succeeded, because it was not possible to get the iron of uniform thickness, and thus the surface of the wheel, after turning, was varied in hardness. The former system of steel face without an iron covering was reverted to, and the tires were completely turned before being put on the wheels and quenched; but after that process the result was somewhat irregular. That irregularity was remedied by grinding, performed by putting on a slide rest a grindstone revolving at a very high velocity, while the wheel to be ground revolved slowly in an opposite direction, and thus a result was obtained which could not be effected by the turning tool. The grinding process, however, he had found an expensive one; and it was questionable whether that mode of manufacture would pay. It had been shown that the German railways which adopted that system made far larger profits than the English lines, although the fares were lower; but, although that was evidence of general good management, it did not serve to clear up the doubts which might arise in relation to individual instances.

Until disproved by the actual figures, he should doubt whether a better tire, viewed commercially, could not be obtained either by turning or by the system of endless rolling. He had seen, with great admiration, the contrivance used in the figure called 'the new system,' for getting over the difficulty, and alluded to by the Author, of the unnecessary use of a costly material. No doubt many present had seen the specimens of Bochum steel wheels that were shown by Messrs. Naylor and Vickers in the Exhibition of 1862; but those had the same expensive material in the body of the wheel as in the tire. He could well understand how natural it would be to endeavour to save this cost by putting a cheaper material into the wheel centres, but he should have feared that, however desirable it might be to do so, every one would be deterred by the difficulty of making the weld, and he was much struck with the good workmanship which must obtain to enable a sound and efficient weld to be made between a fibrous iron centre and a steel tire, in the way shown in the drawing. Those who had the ability to carry out such workmanship, deserved every praise at the hands of practical workers in iron.

If he were in order, he wished, as bearing on the subject, to allude to some wheels of French invention, which were then being made in England. Those were spoke-wheels, but manufactured in a way different to the ordinary one, viz., by one blow of a hammer. That was effected by laying together the boss, the spokes, and the inner rim, in separate pieces, in the form desired when the wheel was finished: those were put into a furnace large enough to receive them, when placed together in the form of a wheel, were heated to a welding heat, and then taken out in a clip and put into a bottom die made to the figure of the finished wheel; and then a top die of a similar figure came down, with a force due to a fall of 4 or 5 feet, and a weight of some 10 tons, and by that one blow all the parts of the wheel were absolutely welded together and completed of the true shape, except a little surplus metal which exuded at the junction of the dies, and that was trimmed off when the wheel was removed from the dies.

There was another kind of wheel manufactured in England, which was also a foreign invention: it was a very ingenious, though simple thing. There were in common use in England wrought-iron spokes, cast into a cast-iron boss, and also wheels formed entirely of wrought iron, in which the spokes and the boss were welded together, either by the old hand-process, or by the plan he had just described; but those wheels solidly welded together were, even when done by machinery, very expensive; while the cheaper mode, that of casting into the boss, was, to a certain extent, unsatisfactory. There was always a fear that the metal of the boss might be blown; and to lessen the chance of this, bosses had been made of dimensions far greater than was needed if the casting were sound; that was to say, for a railway wheel 2 feet 9 inches diameter, a cast-iron boss of 13 inches diameter and 7 inches thick, was not unfrequently used; that was a useless lump of cast iron, employed only with the object of preventing splitting in the contraction of the metal.

The second foreign invention of which he wished to speak was devised with the view of making a wheel which, although perhaps not quite equal to the welded wrought wheel, should be far superior to that of having the spokes cast into the boss. The plan pursued was, to place together the spokes in the required form, to heat them to a red heat, and to lay them on the lower half of a wrought boss at a welding heat; then to take the other half of the wrought-iron boss, also at a welding heat, and place it on the spokes, and by a powerful blow bring the top and bottom parts of the boss together. Those parts became welded, the one to the other, and the spokes cut their way into the plastic mass of the boss, and thus there was produced a wrought-iron boss to closely grasp the spokes, instead of a cast-iron boss; and that could be done at a cost little if anything above that of a cast-iron one. The reason that that mode of manufacture was so much cheaper than that in which the spokes were really welded to the boss, was, that if the spokes were brought to a welding heat, it was necessary to form them of special rolled iron, or of forgings, to provide for the waste that took place on getting them to a welding heat; but when a red heat only was given to the spokes, this waste did not arise, and therefore the ordinary flat bar could be used for those spokes, in the same way as it was used when the spokes were cast into the boss.

The wear of wheels consequent upon the action of the breaks had been alluded to, and it had been pointed out how much the wear was increased by the frequency of stoppages at stations. In his opinion, the injurious effects of breaks were much aggravated, in England at all events, from putting too good work into them. In a break-carriage, or in a tender having two pairs of wheels, there was usually a shaft, working accurately in its bearing, and having a lever upwards and another lever downwards; from those levers, rods extended which worked the break block; those rods had contrivances to alter their lengths, and it was sought by those means to adjust the blocks so that all should bear upon the wheels; but as a matter of fact, that end was not attained. He had, for some years past, made it his business to watch the break-carriages as they arrived, and he had no hesitation in stating, that if the carriage had two pairs of wheels, in three cases out of four one pair was stopped while the other pair continued to run; while if it had three pairs, it was rare indeed that one of those pairs did not continue to run, and more commonly two out of the three continued to do so. That of course arose from the impossibility of adjusting the blocks correctly. It might be asked, why was it so necessary to adjust the blocks correctly in the first instance, since the block which was prominent must soon be ground down so as to come to its bearing? But that opinion, although commonly entertained, was, in his judgment, an erroneous one, as the prominent block seized the wheel, and prevented its further rotation; while the non-prominent block, although not near enough to stop the wheel, was near enough to be ground away, and thus always remained away from its work. All this difficulty, however, would be obviated if the work were done a little less well; that was, if instead of making a truly fitting hole for the shaft, Engineers would be content to put the shaft into a slotted hole, so that it might shift a little, just so much as would insure that the break-block on one pair of wheels should be the abutment for the other block, instead of leaving the bearing of the axle to become that abutment. That was done in America: there, the large eight-wheeled cars had a break-block to each wheel, and yet each block was made an abutment for the other, so that it was impossible to break one wheel with more or less power than another.

Both on the ground of safety to the train, and on that of the wear of the wheels and rails, the proper action of the breaks was a most important subject, and he could not help fearing that, in this country, it was the constant practice to expend a large sum in the construction of breaks, and then to succeed only in obtaining a bad result; while in America, a cheap but judicious construction obtained a far better result, and he thought this unsatisfactory condition of things arose from the subject not having met with due consideration.

Mr. G. H. PHIPPS remarked, that of late years much had been said on the importance of giving elasticity to railway wheels. That object had been attained in engine wheels by means of steel springs inserted between the felloe and the running tire. The disc wheel now under discussion seemed to be wanting in the property of elasticity, and he would expect to find it very harsh and unyielding. No doubt the curvature of the transverse disc did afford some small proportion of elasticity; but in proportion as the disc wheel was harsh and unyielding, the successful use of it militated against the views he had just alluded to.

Mr. C. H. GREGORY, V.P., thought the information they had before them, on the wear of the tires of disc wheels, would have been more useful if it had been supplemented by comparative observations upon the wear of tires on ordinary wheels under similar circumstances. A disc wheel of iron suggested to most minds the idea of rigidity, and he believed that there would be difficulty in getting out of a disc wheel the amount of elasticity which he liked to see in a wheel, without making it unduly weak; and while most people admitted the advantage of hardness of surface both for tires and rails, he thought it was generally agreed that there was some advantage in not having too much rigidity, either in wheels or permanent way. The statements which had been laid before the Institution, of the results of placing a spring between the tires and the rims of wheels, seemed to show, that elasticity produced a satisfactory result in regard to wear; but if it could be shown that the disc wheel possessed advantages over the spoke wheel, the inference might be that they would do well to return to the old form of wheel with a cast-iron boss, which approached more nearly to a disc wheel than the modern type with a wrought-iron boss.

Incidentally to the question of rigidity, he considered that the permanent way alluded to by Mr. Rochussen, in his verbal observations, in which the metal was of very deep section, and weighed as much as 195 lbs. to the yard, must of necessity be very rigid, and that it was not likely to be a good running road. In a commercial point of view it had this obvious disadvantage, that when the surface was worn out, they would have to replace metals of great weight instead of from 60 lbs. to 80 lbs. to the yard, or less.

With regard to the American disc wheels, their introduction was one of the many instances in which the institutions of that country had been adapted to its wants. In those parts of North America where the railway system was first largely developed the extremes of climate were said to have had an injurious effect upon the ordinary wheel first used—a wheel with a wrought-iron skeleton and a cast-iron boss, and the trial of one summer and one winter reduced them to a dangerous condition. The American Engineers met this difficulty by adopting a cast-iron disc wheel, of the charcoal iron of the country, which was of very good quality. He had seen some corrugated discs in cast iron resembling the wrought-iron wheels of which the Author had exhibited diagrams, but the most usual form had two dished discs, separate at the boss and meeting at the rim, cast with a core afterwards drawn out through holes in the discs, the tire being cast in a chill, in one piece with the wheel. He was surprised to hear how rarely these wheels failed in America—how well they stood their work—and their long life; still they seemed to him to run hard, and he thought they could not be good for the permanent way.

Having called attention to the necessity for having comparative statistics of the wear of different wheels under similar circumstances, he would add that the effect of the wheel upon the rail should not be lost sight of, and that in considering the merits of a strong permanent way or a strong wheel, they should endeavour to ascertain what would be the effect of either upon the other; so that durability in one part of the system might not be sought at the expense of short life in another part.

Mr. ROCHUSSEN considered the defects of the American cast-iron wheels were heating under the break, and brittleness when passing through snow or a pool of water. As to the combination of that iron by welding, the great advantage of a wheel so made was its elasticity, and the whole secret was, that when the tire was run down to an inch, or three-quarters of an inch, its elasticity became complete from the vibration running through the wheel. With respect to the combination of the wrought-iron disc and welded tire, that wheel was attempted to be worked in Belgium, but it was found to be faulty, owing to the clumsy method of forming the disc. The great advantage of manufacturing by rolling instead of stamping was, that by continual rolling the wheel became elastic, while by stamping, all the rigidity was produced which it was desired to avoid.