Mr. HUNTINGTON said the question of tramways had taken such a footing in English construction that it was quite time to have a fair and deliberate discussion concerning it. Tramways would in future form an important part in conveyance, especially in situations where the cost or the site of a railway might be inexpedient, and that not only in England, but also in the Colonies and in other places where English skill might be called for. He regretted that the Author had given so little information as to the cost of the different systems in relation to the actual construction. The statement that the cost varied from £1,500 to £6,000 a mile was very vague. He had been interested, as a shareholder, in undertakings of that kind, and had found the information given at public meetings to be of an unsatisfactory character. In London certain tramways might be said to be in full working condition, such as the North Metropolitan and the London or South system; in Dublin also they had been at work for a long period. Some were worked by horse contract, like the North Metropolitan, and others horsed themselves, like the London and the Dublin. The capitals of the companies varied considerably, as also did the results of working the roads. In making a comparison, in addition to the tramways, he had thought that it would be instructive to join thereto the railway system and the omnibus system, for which purpose he had selected the Metropolitan, the Metropolitan District, and the North London railways, as a group approaching the nearest to the tramways for conveying passengers. The length of the North Metropolitan tramway was 30½ miles, of the London, 20¼ miles, and of the Dublin, 15 miles: the length of the group of railways was 32 miles; and the General Omnibus Company covered a range of 58½ miles. The cost for six months to the 31st of December, 1876, of the North Metropolitan had been £22,447 per mile; of the London, £20,697; of the Dublin, £17,125; of the group of railways, £578,320; and the capital of the General Omnibus Company was equal to £10,264 per mile. To put the North Metropolitan on a fair level with the others, the cost of horse stock and equipments (on the London scale) should be added, or £3,040 per mile, making that system cost £25,487 per mile, or about £6,000 per mile dearer than the London. The item "Tramways," which included the roads, paving, engineering, extra works, preliminary and parliamentary expenses, cost on the London £15,005 per mile, which might be analysed thus:—

	£.
Double line of tramways	3,000
Paving, 6 yards wide	8,000
Engineering	1,000
Extra works, &c.	2,000
Parliamentary, &c.	1,000
	15,000

Besides these expenses the London cost £2,177 per mile for horse stock, also £1,959 per mile for cars and other plant, and £1,555 per mile for land and buildings; while the cost of the North Metropolitan for the last two items only was £1,077 and £1,345 per mile respectively. Taking the single passenger as the unit, the North Metropolitan carried 2,457 per mile per day; the London, 2,070; the Dublin, 1,150; the railway group, 7,735; and the General Omnibus Company, 2,450. The receipts per passenger were: North Metropolitan, 2·08*d.*; the London, 2·10*d.*; the Dublin, 2·88*d.*; the railways, 2·57*d.*; the General Omnibus Company, 2·53*d.* The horsing of the North Metropolitan was done by the General Omnibus Company, and the contract amounted to 0·88*d.* per passenger; the London horsed itself, and the cost, including renewal of horses, was 0·81*d.* per passenger, and the Dublin cost for horsing and renewal, 0·88*d.* The locomotive cost on the railways was only 0·35*d.* per passenger. The cost per passenger for the horsing of the General Omnibus Company was 1·31*d.* With regard to the railways, the returns contained the gross receipts for goods and the total gross receipts, so that the gross passenger receipts could be ascertained; but, as far as expenditure was concerned, the returns combined both, and a separation therefore had to be made by computation and approximation. The total cost under each system respectively was: North Metropolitan, 1·51*d.*; the London, 1·57*d.*; the Dublin, 1·88*d.*; the railways, 0·88*d.*; and the General Omnibus Company, 2·11*d.* per passenger. The general results showed that the railway system had at all events the advantage of economy. The probable cost of steam on tramways had been stated by the Author as 25*s.* 1*d.* per car per day, which nearly agreed with his own calculation. He had not taken into account, what the Author had included, the renewal of engine, &c.; in the Tramway reports he found it as renewal of horses, plant, and other matters, and left it to stand as the equivalent of the new form of renewal.

	s.	d.
Fuel, 7 cwt. (during eighteen hours)	7	11
Engineman and stoker at 6s. per day above the present wages of driver	6	0
Sundries, oil, waste, tools, materials, assistance, &c.	1	10
Interest on capital for reforming road and stock	2	10
Contingencies	1	5
Renewals, now charged for horses $\frac{1}{8}$d. per passenger	5	2
Total per car per day	25	2

Therefore, withdrawing the renewals from this estimate as being elsewhere included, and taking the steam alone, he calculated the amount to be as nearly as possible £1 per car per day. Thus the cost on the North Metropolitan, running one hundred and forty cars per day, would be £140; and applying that to 14,000,000 passengers in the half-year, the amount was 0·44*d.* per passenger; also in the case of the London it was 0·45*d.* That gave a *bonâ fide* gain of about 0·4*d.* in favour of mechanical motive power, which was equal to an increased dividend of 8 per cent. or more. By comparing the tramways with the railways in the subjoined table it would be seen that, although the system by steam had great advantages in large cities, where passengers were numerous and distances short, the cost of steam was considerably augmented in country districts, where there were fewer passengers and longer distances to travel. During the six or seven years that tramways had been working, roads, cars, plant, and horses had been more or less subject to renewals. The roads cost about £4,000 per mile, double line, including engineering and other matters exclusive of the paving. Up to the present time the total renewal from the 1st of January, 1871, of the tramway upon the North Metropolitan had amounted to £601 (or £777 including the contractor's outlay) out of £4,000, and on the London to £936. If renewals went on at that rate previously a considerable period would elapse before the tramway was thoroughly worn out; but there was a slow annual increase in this item, which in 1871 was about £88, and in 1876 became £220 per mile on both tramways. With regard, however, to the cars and other plant, the original outlay was £1,133 per mile on the North Metropolitan, and the company had already spent in renewal £1,311. On the London the original cost was £1,919 per mile, and up to the present the repairs had amounted to £1,442, so that the American statement of a ten-years' life did not appear to be borne out. For horses the original. cost per mile on the

London amounted to £2,480, and the renewal to £1,540. The actual reserves in hand to meet the renewals exclusive of these annual outlays were for the North Metropolitan £738, and for the London £595 per mile; insufficient sums, seeing that the annual outlays were already £250 per mile for roads, cars, &c., and £142 per mile for horses. With regard to the tramway itself, he had received the following particulars three or four years ago from a gentleman connected with the construction of the line. The price of iron, timber, and labour was constantly varying at the time, so that the figures could not be taken as an accurate estimate of what the real cost had been:—

	Per yard. s.	d.
Rails, ties, spikes, bolts, dogs, fishes, &c. (rails 50 lbs. per yard at £10 10s. delivered)	10	6
Timber creosoted and shaped	2	0
Fixing and laying, including crossings	1	0
Maintenance for one year	0	6
Contingencies, cartage, lights, watching, waste, and cutting	1	6
Risk and profits 10 per cent	1	6
Total	17	0

1,760 yards at 17*s.* = £1,496, say £1,500 per mile of single line.

Paving with 7-inch cubes of granite for a double road with concrete bottom cost:—

	Per square yard. s.	d.
Granite paving set to tramways, 18 feet wide, materials and labour	11	0
Concrete, averaging 6 inches thick, including excavation and removal of road	1	6
Contingencies, grouting, carting, watching, removing materials, and sanding	1	0
Maintenance for one year	0	3
Risk and profit 10 per cent	1	3
Total	15	0

1,760 × 6 × 15*s.* = £7,920, say £8,000 per mile of double line.

He had also obtained the following particulars:—Gauge, 4 feet 8½ inches with a 4-feet midway. Rails, dogged on kyanised longitudinal bearers 21 feet long, with four transverse bearers bolted with ¾-inch bolts and nuts to the gauge, the weight being, as computed after measurement, 45 lbs. per yard. The gauge was kept by the paving. The dogs were 4 inches long, ⅝ inch in diameter, and were driven into drilled holes on both sides of the rails, slightly angular, about 3 feet apart, one side dividing the space with the other. The dogs were driven into the timber after being well screwed down by a double-sided square-threaded cramp. The joints were fished with plates 9 inches long, ⅜ inch thick, let into the longitudinals. The timbers were bedded in Portland cement concrete 6 inches thick, and the paving was laid upon the same. The sifted rubble of the road was used for grouting, and fine red sand was laid above all. The paving extended 1 foot 6 inches on each side of the outer rails, 7-inch granite cubes being used. Extra works, crossings, and sidings, were not included in the above estimates. The following table illustrated the foregoing remarks more exactly:—

DETAILS of the COMPARATIVE COST of CONVEYING ONE PASSENGER by TRAMWAY, OMNIBUS, and RAILWAY; the TWO FORMER SYSTEMS for ONE YEAR ENDING the 31st of DECEMBER, 1876, and the RAILWAY SYSTEM for ONE YEAR ENDING the 31st of DECEMBER, 1875.

Item.	Tramways.			Omnibus.	Railways.[1]	
	North Metropolitan.	London (South).	Dublin.	London, General.	North London, Metropolitan, and District.	Nine great trunk lines from London.
	d.	d.	d.	d.	d.	d.
Horsing (net)	0·897	0·808	0·761	1·139	..	..
Renewal of horses	..	0·156	0·099	0·215	..	..
Locomotive, passengers only	..	..	..	..	0·348 (Locomotive, Wages, Miscellaneous)	1·745
Wages	0·358	0·349	0·482	0·490		
Miscellaneous	0·066	0·091	0·083	0·019		
Repairs of cars	0·067	0·090	0·101	0·136	0·076	0·476
„ road	0·060	0·072	0·157	..	0·123 (road and plant)	1·286
„ plant	..	0·016	0·027	0·062		
Rents, rates (net)	0·047	0·127	0·095	0·058	0·076	0·275
Duties	0·006	0·009	..	0·006	0·094	0·500
Compensations	0·007	0·025	0·026	0·012	0·015	0·228
Law and parliamenty.	0·023	0·026	0·034	0·031 (Law and General)	0·151	0·804
General (net)	0·010	0·013	0·041			
Total cost	1·541	1·782	1·906	2·168	0·883	5·314
„ receipts	2·078	2·076	2·895	2·552	2·576	13·031
Gross profit	0·537	0·294	0·989	0·384	1·693	7·717
Capital expended per passenger, adding horses	6·856	6·420	10·382	2·800	31·160	99·520
Passengers per mile per day	2,405	2,104	1,106	2,400	7,735	117
	£.	£.	£.	£.	£.	£.
Cost per mile	25,487	20,697	17,125	10,264	578,320	58,245
Miles open, all as in double line	30½	20¼	15	58½	32	5,875

[1] The cost of goods is eliminated from the railways.

Mr. Head had not studied the subject very much, but he had had a great deal to do with traction engines on roads.[1] In considering the application of steam to tramways, it should be remembered that the gradients could not be altered, so that the engine had to work upon a variety of gradients according to circumstances. Two kinds of engines—separate and combined—had to be constructed for tramway cars. There were many advantages in the separate engines constructed by Mr. Merryweather and Mr. Hughes. The companies using those engines could employ their present rolling stock; the passengers had not the same fear of being blown up if the boiler should burst as when the engine and car were combined; and the public had an idea that the system was the right one from association with railway trains. At the same time, looking at the gradients of the lines in London, Edinburgh, Liverpool, and other places, he thought there would be a good deal of difficulty in getting an engine weighing from 4 to 5 tons up some of the inclines in wet, foggy weather. It was difficult, however, to bring data forward of what could be done under such circumstances. The experience with traction engines on roads showed that in damp weather adhesion was small. Horses could always haul the cars, for, if two would not suffice, a third, and even a fourth could be added; but if an engine could not get on in wet weather the whole traffic might be blocked. With an engine on the principle of Mr. Grantham's there was the whole of the adhesion from the combined weights of the engine and boiler, the car, and the passengers. It was unnecessary to say that adhesion was practically the keystone to the propelling power of the car, and that an engine of great weight had more power to propel itself than one of light weight. These important matters must be cleared up before tramway companies could decide upon the best engine to be employed. There might be one or two level lines on which a separate engine could be used with advantage, but he thought there were many lines in London which could only be worked safely with a combined engine and car.

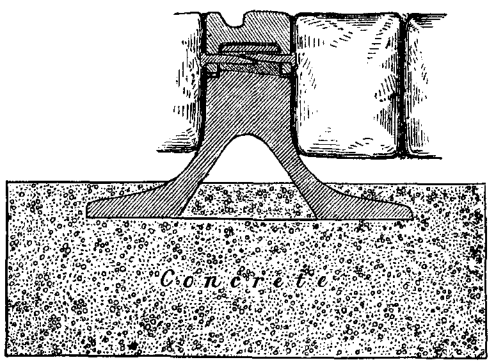
Mr. Longridge said it was evident that separate engines could only be employed where there were easy gradients. He had seen an engine of Mr. Merryweather's at Vienna, and it struck him at the time that there would be considerable difficulty with a steep gradient. It weighed $3\frac{1}{2}$ or 4 tons, and, including car and passengers, the total weight would be about 10 tons. With a gradient of 1 in 20 that weight would require a tractive force of

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxvi., p. 36.

about 1,482 lbs. He took the friction of the engine at 20 lbs., and of the car at 15 lbs. The insistent weight was the weight of the engine itself, 4 tons, and he believed that in ordinarily slippery weather the adhesion would be not more than one-tenth, or 896 lbs. Under those circumstances he did not think it possible to work with any satisfaction. Much the same thing applied to Mr. Grantham's car, which he also saw at Vienna. It went very well on level ground, or on a moderate inclination, and there was no nuisance from blast, sparks, or smoke; but in that case the engine was placed at one end of the car, and the driving wheels beside the engine. About two-thirds of the way towards the other end there was a bogie with four wheels, and the only adhesion that could be obtained was the adhesion upon the driving wheels of the engine, which would not amount to more than one-half of the total weight. The same difficulty therefore arose as in the case of Mr. Merryweather's car, and he knew that considerable trouble had been experienced at Vienna with a gradient of 1 in 24 when the rails were at all out of order. It was not only the slipperiness of the rails that affected the tramway, but their inequalities. The constant passage of heavy traffic made it impossible to keep the rails in the same order as on a railway, so that one wheel would perhaps bear scarcely at all on the rail, and the other would bear very heavily. For steam traction it would be necessary to devise some means of utilising the whole of the carrying wheels of the car, and that he thought might be readily accomplished with Mr. Grantham's car. Another difficulty in the way was the great variation in the work to be done at different times. In the case of Mr. Merryweather's car, running nearly empty on a level, at 8 miles an hour, a tractive force was required of 2½ HP., whereas on a gradient of 1 in 20, a tractive force of 19 HP. was needed. With the small boiler necessarily used in such cases, he considered it would be difficult to regulate the fire and the generation of steam so as to meet those varying conditions. The steam would sometimes blow off with violence, which would be objectionable, and would perhaps be experienced with almost all steam engines. No doubt many objections would be avoided by the use of compressed air, but that was an extravagant mode of getting power. Compressed air was not itself a motive power, but only a method of applying it, the power being in the steam engine which compressed the air. M. Mékarski found that for every horse-power, effective, obtained in compressed air, an amount of 5 steam HP. was needed, so that the power actually used was only 20 per cent. There appeared to be an error in the Author's comparison of the pneumatic car with steam power. He estimated, for instance, the fuel by steam power at 5*s.* per day, and in the pneumatic car at 2*s.* 6*d.*, whereas if M. Mékarski was right, it should be five times as much. A combination of compressed air and steam had been brought under his notice, the power being obtained by the explosion of ordinary coal gas. It seemed ingenious and likely to prove of value. It avoided all the difficulties arising from noise, smoke, and the like, and was always perfectly at command, since it could be varied almost at any moment from 2 HP. to 20 HP. Although gas, as fuel, was expensive, he thought the expense would be far more than counterbalanced by the great advantages that would be obtained.

Mr. A. M. Fowler said, in Salford 22 miles of tramway were being laid down, and great anxiety had been felt as to the best mode of construction. He was surprised to find that the Author had come to the conclusion that a timber foundation was the best for large towns. With regard to side fastenings, he agreed with the Author, that unless the paving stones were brought close to the iron the necessities of the case in regard to heavy traffic in large towns could not be met. In Salford a system had been adopted (Fig. 1) to

Fig. 1.



which the objections raised in the Paper were not applicable. There was a deep flange under the rail, a close joint to the iron, and by having a fastening every 3 feet it was impossible that the traffic could produce any detrimental effect upon the surface of the street. The paving setts were bedded in ashes on the top of the concrete. The first portion of the line had been laid about two months, and although the traffic had been heavy there was no crack or break in the joints of the paving. Before the Salford committee decided upon that plan, they had visited almost every town in

England where the best-known systems of construction were employed, and, after his report, they came to the unanimous conclusion to adopt that system. The Author had stated that, by having the timber foundation set back from the face of the rail, the fastening was made flush with the side of the rail. That allowed for the width of the dog, or the fastening, and it allowed for the sett to come close to the rails. In tramway construction the object was to preserve the foundation, and if it was preserved by keeping out the water, vibration was to a great extent prevented. He did not suppose that the setts were grouted, as in London, with lias lime, or, as in Lancashire and Yorkshire, with asphalt concrete; the space would require to be filled up, otherwise the water would get in, and so it would work loose. He thought the asphalt or concrete would not adhere so well to timber as it would to iron, and that a continuous bearing was objectionable. If the vibration of the rail was to be reduced to a minimum, the bearings should be about 2 or 3 feet apart. In the old plan of railway construction, with longitudinal timbers, the vibration in the foundation had been so great, that transverse sleepers had been resorted to. If such sleepers were laid solid throughout, the structure would not be so good. With a rigid longitudinal foundation, packed hard in the centre, it must necessarily tilt, just as a flag in a street would when not bedded well at the corners. He did not wish to say anything against a continuous iron bearing, or a foundation of iron under a portion of the setts; but he maintained that if there was not a uniform foundation for the setts they would tilt. He had found that to be so in tramways already constructed on that principle. Railways were generally level, as compared with tramways, the latter having to be regulated according to the inclination of the streets; and he did not think it would be safe to construct tramways of steel where the gradients were as steep as 1 in 20. On that ground he had adopted the old iron rail. He did not agree with the Author that the fastenings of timber should be more numerous. If the fastenings by dogs were numerous, there would be a tendency to split the timber, and the wear would not be so permanent.

Mr. LIVESEY described a road that had been largely used in South America, composed entirely of iron and steel. Seven years ago he designed for Buenos Ayres a tramway in which the rail was of steel, and the channel dovetailed, so that the fastening would not project and interfere with the stones. More than 100 miles had been sent to South America, and laid down in the interval. In Buenos Ayres the timber roads were being taken up and relaid with iron

D 2

roads, which were much more durable, and in the end more economical. He greatly preferred steel rails to iron rails whenever the capital could be afforded, as the former did not wear so soon; indeed some of the iron rails had already been renewed. He believed that an iron permanent way would ultimately supersede the use of timber, and that an iron road with a steel rail would last thirty or forty years, if not longer.

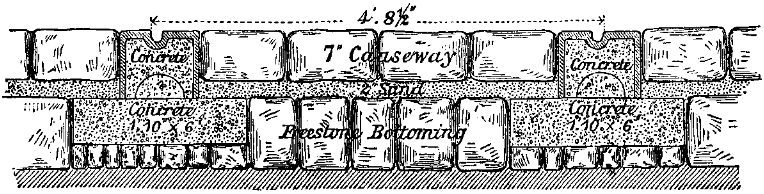
Mr. J. H. LYNDE remarked that the traffic on tramways was different from that upon railways, and that the pavement abutting upon the rail was subjected to much extra wear and tear by the ordinary traffic. Thus it was important that this part of the pavement should be provided with such a foundation as would prevent the subsidence of the setts, which had proved to be the great objection to the introduction of tramways. As the pavement was practically rigid, so the materials used in constructing a tramway should be rigid; moreover the materials should not be liable to decay. The tramway adopted in Manchester fulfilled these conditions. The foundation was a continuous series of cast-iron bearers provided with side flanges for the support of the adjacent setts, and a deep groove on the upper surface for the reception of the tongue of the steel rail, which was keyed down by means of wedge cotters passing through the cast-iron bearer and the tongue of the rail. No difficulty had been experienced in laying the tramway, and as much as 220 lineal yards complete had been executed in one day by a gang of sixteen men. The cost of this system, which was known as "Barker's Patent," varied from about £2,000 to £2,300 per mile, according to the weight of metal and depth of pavement used. The Manchester line consisted of 212 tons of cast-iron bearers and 63 tons of steel rails to the mile of single line. One great advantage of this tramway was, that the rails could be renewed with but little interference with the cast-iron bearers or the pavement, and, also, that the delay and difficulty of using concrete were avoided, except in rare instances of soft foundation.

Mr. LAWFORD agreed with the views of the Author, with one or two exceptions. He had stated that asphalt and wood paving had always proved failures. On the south side of London there was a tramway the first 400 yards of which were paved with asphalt. There were stone setts on each side of the rails, and also at 18 inches outside the rail where it joined the macadam; and it was as good a piece of tramway as could be seen. The mischief arose where the asphalt joined the macadam, and there there was a series of ruts. The same remark applied to wooden pavement. About 200 yards of similar tramway, near Clapham Rise, were paved entirely with wood, for the purpose of deadening the sound in front of the Home for Incurables. Whatever the pavement was, it should, he thought, be carried across the road; and in that case as good a job might be made with wood or asphalt as with stone. The only other matter on which he disagreed with the Author was with regard to cost. He should like to see a street tramway made for £1,500 a mile. He had made the Duke of Buckingham's tramway, which was not, strictly speaking, a street tramway, but it crossed wide public and turnpike roads. It was 8 miles in length, and had been in existence nearly seven years. The rails, weighing 30 lbs. to the yard, were laid on longitudinal sleepers, and the gauge was 4 feet 8½ inches. For the first twelve months it was worked entirely with horses, and since then it had been worked by steam, which had proved more economical. Two of Aveling and Porter's traction engines had been built for the purpose, fitted with flanged wheels, and they had acted extremely well. The speed was from 4 to 8 miles an hour, the average being about 6 miles. Within the last six months a small four-wheeled coupled locomotive, rather lighter than a traction engine, had been introduced. The manager of the line had informed him that the cost of haulage by horses was £1 12*s*. 11*d*., as against £1 by steam; adding, "in my desire to be impartial, I think I have rather underestimated the cost of horse haulage." The maintenance of the line, exclusive of renewals, was £63 7*s*. 6*d*. per mile per annum. The steepest gradient was 1 in 45 for about ¼ mile; the others were easy, practicable gradients. It was a single line with sidings, and was made at a cost slightly under £1,400 per mile, when rails were rising considerably in price. No mention had been made of the internal dimensions of the cars. On the south side of London the directors tried to pack eleven people inside. He thought there should be a division into two classes, as on the continental tramways. A premium had been offered by the General Omnibus Company for the best method of checking the fares. He did not know whether a mechanical mode of checking the takings of the conductors was possible; but a move had been made in that direction on the south side of London; one uniform fare was charged for any distance, and as each ticket was punched, a little piece of paper fell into a box (not under the conductor's control) with the operation.

Mr. Rapier said, several years ago Mr. Deas, M. Inst. C.E., consulted him as to the best way of obtaining some easement to the traffic along the Broomielaw, Glasgow. At the time he referred

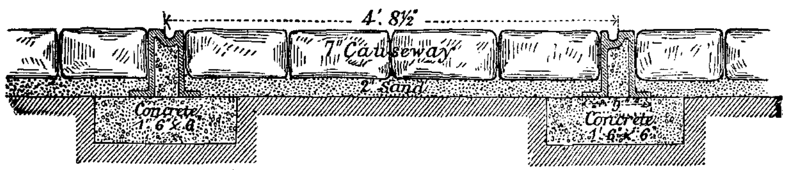
Mr. Deas to the tramways for ordinary street traffic at Ipswich, and in the Devonshire Street goods yard, which had been worked for twenty years without repairs, not subject, however, to such incessant traffic as that of Glasgow. The result was the construction of the tramways on the principle shown by Figs. 2 and 3, in which

Fig. 2.



Cast-iron Tramway for dock purposes for flanged vehicles, or ordinary street lorries, as laid on the Glasgow Quay.

Fig. 3.



Tramway for flanged vehicles only, as laid at the Glasgow Gasworks.

it would be seen that the bottom flange was discarded. These tramways had been in constant work for seven years, and had not cost sixpence a mile for maintenance or renewal, or repair of any kind. At first it seemed desirable to have a bottom flange at the outside of the blocks, but it was found inconvenient in fixing the paving setts. The bottom flange was then put on the inside; that did very well, but, economy being the order of the day, it was cut away altogether with the most satisfactory results. The blocks, which were adapted both for flanged and unflanged vehicles, were cast with recesses at the ends to receive fish-plates, which were bolted in the ordinary manner. The blocks were entirely filled with concrete composed of 1 part of Portland cement and 7 parts of gravel and sand well punned in, and allowed to lie three or four days to set. The road was made like an ordinary first-class street or dock road, with the bottom in dry rubble, and a base of concrete was prepared for the tramway blocks, 1 foot 10 inches wide and 6 inches thick. The tramway blocks were then turned over and were fixed with Portland cement to the concrete bed. In a few instances, where the blocks had to be raised for laying water or gas pipes, it was found that they had stuck to the concrete beneath, and had to be actually cut away.

The cost of these two sections was—

	Fig. 2.			Fig. 3.		
	Cwt.	qrs.	lbs.	Cwt.	qrs.	lbs.
Weight of cast-iron blocks, per lineal yard	3	2	14	2	3	0
	£.	s.	d.	£.	s.	d.
Cost of cast-iron blocks, per lineal yard .	1	5	4	0	19	0
Cost of concrete for filling and foundations, per lineal yard	0	4	8	0	3	3
Cost of laying blocks, per lineal yard . .	0	2	6	0	2	3
Total cost per lineal yard	1	12	6	1	4	6

Such a road was, of course, contrary to all preconceived notions. Though elasticity had been constantly advocated, this road was thoroughly rigid. The blocks, once laid, remained there. At first tie-bars were used, but it was found that they were not necessary, because the blocks could not be got to stir even when it was required to move them. The first part of the tramway had been laid seven years. Shortly afterwards the price of iron rose so rapidly that he ceased to think about the matter; but when the subject was about to be brought before the Institution he wrote to Mr. Deas, and received the following particulars:—From one hundred to one hundred and forty railway trucks went over the busiest part of the tramway daily, which was equal to a vehicle twice the weight of a tramcar passing every five minutes. He had inquired whether any regular railway locomotives had passed over the line. The reply was that none had done so; but that contractors' locomotives constantly passed, often dragging heavy loads upon bogies to the 60-ton crane. The highest speed of the railway vehicles was about 5 miles an hour, and of the street lorries 6 miles an hour. The tramway was chiefly designed for street or dock lorry traffic, which in Glasgow was very heavy; and it was a noteworthy circumstance that, if horses had to turn off the tramway, they always went back again of their own accord. The tramway was made of cast iron; he had therefore asked Mr. Deas how many blocks had been broken, and the reply was, "Not one." The blocks were ordinarily cast in 5-feet lengths. It was originally expected that in order to get them to lie steady 10-feet lengths would be required; but it had been found unnecessary to increase the lengths, because the blocks never showed any signs of motion. About six years ago 3 or 3½ furlongs of the same kind of tramway, for flanged vehicles only, had been laid in the Glasgow Corporation gas yard, and the manager reported that it had worked very well and occasioned no trouble. The edges had little notches ½ inch wide cast in them, at intervals of 3 or 4 inches, for the use of vehicles crossing the road; and he feared that there might be fractures from that cause, but none had occurred. The only thing beginning to need repair was the granite horseway between. In addition to the tramway along the street, two double lines were laid across the thoroughfare, to obtain access to a railway yard, and the whole of the ordinary traffic along the river-side passed over them, but no complaints had been made of horses falling down. The cost of the tramway had been £3,500 per mile, or £1,000 more than ordinary tramways, if made so as to accommodate unflanged, as well as flanged, wheels. For flanged wheels only, the cost was about £100 per mile more than that of other types of tramway. The latter, however, were now costing £250 a year per mile for repairs, although they were only beginning to get rickety, and no one could say what their condition would be in three or four years. He might add that the traffic on the Broomielaw tramway was incessant.

Mr. C. H. Beloe thought the subject of street tramways had not received the attention which it deserved from the profession. Their construction had been in the hands of comparatively few engineers in England, but the time was coming when works of that kind would be greatly extended. The hurried manner in which street tramways were generally constructed was a matter deserving serious consideration; and it was a wonder the roads stood as well as they did. An effort should be made to obtain from the Board of Trade some relaxation of the rule limiting the amount of roadway to be opened at one time to 100 yards. Local authorities were very severe in enforcing those restrictions upon tramway companies. Companies were often blind to their own interest in urging engineers to push forward their works so rapidly. To assist in rapid work the Author recommended the use of bituminous concrete. He had tried it, but it had not answered his expectations. The Glasgow tramways were laid almost exclusively upon bituminous concrete, and the paving had sunk there to a greater extent than he had observed anywhere else—certainly more than it did upon cement concrete, if time were given for it to set. If any material could be found which would set more quickly than cement concrete, a great advance would be made in the construction of tramways. He agreed with the Author in his approval of cross sleepers. He had recently laid a road with tie-rods. It was a macadamised road with hard rock pitching underneath; cross sleepers would have involved excavating the hard rock pitching, and then the foundation of the road would have been seriously weakened. Under those circumstances he was induced to use tie-rods; but though the expense was considerably reduced, he regretted that he had not taken out the old pitching, and laid a substantial bed of concrete. The box rail was certainly a good one; but having regard to the probability of increased weight on tramways in the future, and to the introduction of steam locomotives, he was inclined to think that the T-shaped rail was the best. He did not object to the use of the rail with the central groove, because he thought it the best form for tramway purposes. The waste of the guard rail, carrying no traffic, was saved, and the whole surface of the rail for the tread of the wheel was utilised. Nor did he think that the flange was weakened, or that the car was more liable to leave the rail. In his opinion a simple form of construction would be two ordinary flat bars set on edge, and secured to cast-iron chairs, resting on cross sleepers. If necessary the chairs could be cast to receive wooden cushions under the rail to deaden vibration; but he believed that by the use of the central groove the width of the rail could be diminished and many other advantages be obtained. He should watch the use of it in Liverpool with great interest. He agreed in the recommendation of tar grouting, which was extensively used in the North of England. The principal objection to it was the impossibility of applying it in wet weather. Borough engineers could stop up a whole street and cover it with a roof under which to carry on grouting operations; but the ordinary tramway engineer was not so fortunate; and hence tar grouting, though most effectual, was useless unless a continuance of fine weather could be insured; because the grouting must proceed as rapidly as the rest of the work, and a few days' rain would spoil the whole operation. He did not agree in the disapproval of cast-iron crossings and preference for cut rails. Cast-iron crossings were not as durable as could be desired, but no doubt in a short time steel points and crossings would be cast, though hitherto he had failed to obtain them. It was difficult to make a neat crossing by cutting iron rails, but it was much more difficult to do so with steel rails. He believed that iron tramways would supersede wooden ones. He had watched the process of laying the tramway in Manchester, and noticed that the workmen had no difficulty in pinning down the rail to the cast-iron sleeper. With regard to the cost of tramways, he thought that a single line, including paving, but without any contingent expenses for engineering or company's affairs, might be set down at from £4,000 to £4,500 a mile. It was difficult to estimate the cost of repairs, although it seemed that there had been a great increase in the cost of renewals and of repairs of late years. He hoped that the new tramways now being laid would show a better result in that respect than their predecessors.

Mr. W. MARTINEAU said his connection with a large tramway car building firm had given him opportunities for becoming acquainted with what had been done in the construction of tramways in England and abroad. In England and Scotland the ordinary 4-feet $8\frac{1}{2}$-inch gauge had been almost universally used. In Ireland the Irish railway gauge of 5 feet 3 inches had been followed, but he thought it was a little too wide for the convenient working of tramways. In a few other countries a narrower gauge had been adopted. Thus the Madras tramway was on the mètre gauge, and the same gauge had been laid in Rome. In the Isle of Man and in one case in Ireland the gauge was 3 feet. He thought there was no objection to the narrower gauges; but whatever the gauge might be, it was of the utmost importance that it should be maintained throughout the whole length of the tramway. Nothing contributed more to the destruction of tramway wheels than a line being a little out of gauge; and wherever wheels were found to wear unduly, the engineer might be almost certain that some part of the line had not been truly laid. He thought that cross sleepers were advisable, and indeed necessary for the preservation of the width throughout.

The weights of the cars and wagons employed on different systems were shown in the following table:—

WEIGHTS of CARS and WAGONS CONSTRUCTED by the STARBUCK CAR and WAGON COMPANY, LIMITED.

		Cwt.	qrs.	lbs.
Carriages—				
London car to seat 22 in and 24 out	weight	49	3	0
Hoylake „ 22 „ 24 „	„	46	3	7
Birkenhead „ 22 „ 24 „	„	47	1	14
Oporto „ 20 „ 20 „	„	40	2	0
Middlesbro' „ 16 „ 16 „	„	34	0	0
Naples open car, with 5 transverse seats to seat 20	„	21	1	20
„ car to seat 12 inside only (with partition)	„	26	3	14
„ „ 16 „	„	34	0	0
Brussels „ 16 „	„	34	0	0
Middlesbro' „ 14 „	„	24	1	0
Sheffield „ 16 „	„	29	0	0
Leeds „ 18 „	„	31	0	0
Tramway goods trucks—				
Pernambuco wagon	weight	29	2	11
Oporto open goods	„	27	1	0
„ covered goods	„	32	1	0

N.B.—The weights given above include wheels and axles.

It would be seen that the weights varied from $2\frac{1}{2}$ tons for a full-sized car carrying forty-six passengers, to as low as 24 cwt. for a light one-horse car carrying fourteen inside. Some heavier cars weighing over 3 tons (not mentioned in the table) had been made for Russia. They had wrought-iron under-framings, iron panels, and elliptic springs. The Author had stated that india-rubber springs might be got to endure every climate, but it had been found that they would not bear the extreme and lasting cold of a Russian winter, for which steel springs were indispensable. The Russian engineers also preferred screw brakes. These things, of course, rendered the car much heavier. Fortunately, St. Petersburg, where tramways were largely developed, was level, otherwise great difficulty would be experienced in dragging the cars. Light one-horse cars had been introduced in England, principally at Sheffield, Leeds, and Leicester; and abroad, in Naples, Oporto, Antwerp, and Brussels; and he thought they would be brought into extensive use. An eminent French engineer, in reporting to the Municipality of Paris about a year ago, stated that the essence of a tramway was to keep up a continuous flow of traffic, so that, as far as possible, a car should always be in sight; and that could often be much more economically attained by a light one-horse car than by heavier cars with two horses. With regard to the duration of cars, the Author stated that cars had run in the United States for twenty years. It should be known that those cars had no top seats, for there could be no doubt that the heavy weight of a top seat, with a number of people on it, did, in starting and stopping, strain the framework of a car, and that therefore cars without such seats lasted the longest. American wheels combined extraordinary hardness in the tire with great toughness in the body of the wheel. There were not many wheel-making firms in America, and the procedure of each firm was to a certain extent secret. A quality of iron was secured which admitted of crystallisation and chill entering a remarkable distance into the fibre of the iron, and a careful system of annealing was adopted after the wheels were cast. The question of the construction of tramways had long since been discussed. He had a plan for tramways for the whole of London, dated January 1851; also a sheet of tramway sections dated 1854, in which most of the points as to the structure of the permanent way of tramways were laid down. He had attended several trials of steam tram-cars, and it appeared to him that on a level line little difficulty was experienced. The limit of incline, which the Author had put at 1 in 30 for tramway rails laid in England, was probably reached much earlier than that. An engine was required which would start without hesitation on the gradient, whatever it might be, in all states of the weather; and in order to secure that result, in any particular case, the amount of adhesion was an absolutely known item in the calculation. If the amount of adhesion implied a weight on the wheels greater than the rails would properly and economically carry, the limit was reached, and either heavier rails must be laid or the use of steam be abandoned. The use of steam in each case must be determined by the strength of the line to carry the weight of an engine necessary to work on the steepest incline.

Mr. E. A. Cowper was surprised that an opinion should have been expressed in favour of iron rails over steel rails for tramways. Not only were steel rails stiffer and stronger, but they were harder. A great deal of grinding or wearing of the rails was caused by the grit and sand on the road; and a soft rail would necessarily suffer from that action more than a hard one. Any one who had observed the grinding action of emery would have noticed that it made a much deeper cut into soft iron than into steel. Steel, therefore, was undoubtedly the right thing for tramway rails.

Mr. E. Perrett observed that the Author had not mentioned what he considered to be the immediate cause of the rapid loosening of the spiked rail from the sleeper. It was impossible to suppose that the mere passage of a 5-ton car over a 30 or 40-lb. rail spiked down could loosen it. The cause was rather to be sought in the extremely unmechanical construction of the car. An ordinary London street car weighed when loaded about 5½ tons, was 22 feet in length, and was balanced on a 5½-feet or 6-feet wheel base in order to get round a sharp curve. Oscillation was soon set up, which this wheel base was unable to control; and that had been the chief cause of the withdrawing of the spikes, and the abandonment of a rail which was otherwise cheap and good. He did not think that any rail would long remain secure without a more extended wheel base to the cars running over it. He was aware that cars with six wheels had been tried, but the additional weight was too much for the already overtaxed horses. When steam was introduced, together with suitable rolling stock, that difficulty would be overcome. In the cars with six wheels the wheel base was made flexible, the central pair of wheels having power to travel sideways across the car. He disagreed entirely with the conclusion of the Author that detached engines and cars were superior in nearly every respect to combined engines and cars. Leaving out of consideration such qualifications as absence of smoke, steam, or noise, which both kinds of machines might or might not have, the great requisite for a tram passenger car for use in and about towns was handiness. In this was included, power, to run either end first without turning or bringing the engine round, to ascend a steep gradient, to stop quickly in going down, to take sharp curves, and also, what had apparently been lost sight of, power to steer. The detached engine failed in all these important particulars, the combined engine need not fail in any one of them. In the case of some combined cars the driver had only to walk from one end to the other on the return journey. With reference to ascending a steep gradient, it might be all very well to increase the weight of an engine from 3 tons to 5 tons to give the necessary adhesion, but that was not the proper way of overcoming the difficulty. A heavier engine than was otherwise necessary to do the work was a faulty machine. A detached engine of 3 tons was not sufficient to draw a car of 5 tons up a moderate gradient. To drag cars on ordinary lines 20 or 30 lbs. to the ton was necessary, and on curves the traction amounted to 50 or 60 lbs. to the ton, so that the limit of gradient was soon reached by a detached engine and car, and to connect the moving parts of the engine to the car wheels to gain adhesion was making a combined car of the worst kind. The disadvantage alluded to by the Author, of an engine drawing a 22-feet car with 8 feet overhang round a curve, was obvious. Suitable cars could be made to be pulled by an engine, but that did away with the argument for the use of detached engines, namely, the possibility of using up existing stock. As regarded steering power this was of no moment with horse cars as the horses gave the necessary list to the cars, but a locomotive must have points and attendants at the branches, whereas with the number of wheels necessary for a combined car, steering could be easily effected. The alleged advantages of a detached over a combined engine were: the power of using up old stock, the power to take two cars on an emergency, greater safety to passengers, and cheapness or facility of repairs. The first was no advantage in new tramways; and in the case of old tramways, especially where outside passengers were carried, he had been informed that the existing cars broke up so rapidly, owing to their unmechanical construction, that no company would care, even if it could afford, to replace the existing stock by steam stock any faster than the existing stock broke up. Independently of that, the existing stock was not fit for steam traction, being far too light. The power of drawing two cars was not peculiar to a detached engine; a combined engine and car was still more capable of taking an additional car. A detached engine was considered by some safer for passengers, but he did not remember any instance in which a locomotive boiler had exploded whilst running. The Author stated that when a combined engine was under repairs £800 would lie idle. That might be so for slight repairs, but it amounted only to this: the cost of a detached engine was about £600 and of an ordinary car about £200; the cost of an engine and car combined was £700; so that there was a saving on the original cost; and in the case of repairs to the engine the difference in the value laid up was only that between £600 and £700, or £100. But if a combined engine and car were properly made, for extensive repairs the engine could be easily detached and another substituted, in which case the amount lying idle would only be £200 or even less. He had constructed a car for experimental purposes, with a fixed wheel base of 4 feet, to which the power was attached, set on a frame that could be easily removed from the main frames of the car. A two-wheeled Bissel bogie at either end gave a 17-feet wheel base. It was capable, nevertheless, of running round a curve of 35-feet radius, and by a steering arrangement at each end, it could be taken on to the road or off the road, or on the branches, without the slightest difficulty; and was free from oscillation. There was a small boiler at each end, connected together, the object being to distribute the weight, and also that the driver might stoke the boiler behind him, whichever way he was going, the two boilers being connected, he knew what was going on in both. The weight of the car when loaded was 8 tons, of which 5 tons were on the driving wheels and available for adhesion. He believed the car fulfilled all the conditions required in a passenger car. Where a tramway was like a light railway, the vices of a detached engine were less apparent, and it might be made suitable for the work, but for ordinary passenger traffic he thought a combined car possessed every advantage.

Mr. C. B. King considered that the car just described would not satisfy the requirements of the public. In Paris, one line of tramways, 5 miles long, was worked entirely by an ordinary locomotive engine, with a special arrangement to prevent the emission of steam and smoke, and it did its work well. He was informed that the cost of steam, as compared with horse traction, was at present as $5\frac{1}{2}d.$ to $7\frac{1}{2}d.$, but this was subject to variations as coal and fodder altered in price. The advantage of a combined car in obtaining adhesion had been mentioned. He, however, preferred a light detached engine. In order to increase the power of adhesion of such an engine many arrangements had been tried, the most effective of which was Holt's system adopted by

Messrs. Merryweather. The engine was coupled to the car by an endless chain, passing round a chain pulley on an axle of the engine, and likewise round another chain pulley on one or both axles of the car. These pulleys were disengaged on the axles by self-acting gear when the extra adhesion was not required; in some cases this chain was driven by an independent auxiliary cylinder, which only worked when going up inclines. This cylinder had a much higher piston speed than the locomotive cylinders, so that a 5-ton engine could work an ordinary car up inclines of 1 in 12 and 1 in 14 in all weathers with ease. He had seen an engine of 3½ tons weight, on one of the North Metropolitan tramways, ascend an incline of 1 in 27, and go round a curve of 35 feet radius, with a car and fifty passengers. He was afraid that Mr. Perrett's car would not pass the regulations of the Board of Trade, one of which was that passengers were not to pass and repass the motive power. He had been informed that on the Paris line the public were at first much terrified at the prospect of an engine going along the road at a speed of 15 miles an hour; but after an experience of six or eight months the idea of returning to the old modes of conveyance had been abandoned. It was found that ordinary vehicles never got on the line, always carefully avoiding it.

Mr. E. Perrett explained that the Board of Trade officials had seen the drawings of the car he had described, and offered no objection to the arrangement.

Mr. Walter Hancock remarked that his uncle (whose pupil he had been) had worked at the subject of steam carriages continuously from 1824 to 1836, and had made eight or nine carriages designed to compete with carriages on common roads. He was obliged to allow for the enormous tractive force required, and for the vicissitudes of the roadway, so that the power of his engines was greatly in excess of that required on tramways. The engines were of three classes. One was a small engine, with 3⅜-inch cylinders, making 150 strokes per minute, for a carriage conveying four persons; another was a 9-inch cylinder engine, with 100 lbs. pressure of steam per square inch, making 100 strokes per minute, for a carriage conveying ten or twelve persons; and another was a 12-inch cylinder engine, with a length of stroke also of 12 inches, for a carriage to take twenty-four to thirty passengers. This was prior to the great improvements in steam engines, so that the consumption of fuel would now be considered enormous. In twenty weeks' continuous working of the "Automaton," the largest engine, when making

100 revolutions per minute, to go 10 to 12 miles an hour, over a distance of 4,200 miles, 700 journeys, and carrying 12,700 passengers, 55 chaldrons of ordinary gas coke were used, equal to 20 lbs. per mile. The total cost was $2\frac{1}{2}d.$ per mile for carrying only half the number that an ordinary tram carriage would carry at a cost of $1d.$ per mile. The engines were made, as all old engines were, with defective valves, it being long before the improvements by Dewrance and others in 1837 and 1838, by which the consumption of steam had been much diminished. Not only was it necessary to carry more coke and more water, but the strength and weight of the carriage were increased, its weight when loaded being from $4\frac{1}{2}$ to 5 tons. In consequence of these experiments a parliamentary committee was appointed, and in their report in 1831 the belief was expressed "that the substitution of inanimate for animate power, in draught on common roads, is one of the most important improvements in the means of internal communication ever introduced. Its practicability they consider to have been fully established; its general adoption will take place more or less rapidly, in proportion as the attention of scientific men shall be drawn by public encouragement to further improvements."[1] Here were none of the timid fears and cautions to be found in the reports of the more recent committees.

Mr. E. Chadwick, C.B., thought that sanitary science might put in an appearance in connection with the subject of tramways. It had long since been apparent that every means of cheapening transit, and facilitating the distribution of the population, tended to diminish overcrowding in urban districts. If things had remained as they were, there might now have been in the metropolis and other urban districts a double and even a threefold population heaped up on the old areas; and however good the sanitation might have been, there would certainly have been increased death rates. His colleagues on the Metropolitan Sanitary Commission had before them the evil of overcrowding. Stone trams were suggested, of which various examples existed, reducing the horse traction more than one-half; but there were obstacles in the way, chiefly administrative, arising from the fact that all the radii out of London were split up into different parochial jurisdictions, there being one for almost every mile of road. This division had added largely to the expenses of all the tramways, and one director had informed him that the dividends of his line had been almost

[1] *Vide* "Report from Select Committee on Steam Carriages; with the Minutes of Evidence and Appendix." Folio: London, 1831.

taken away by the exactions of the separate jurisdictions. He would suggest that accounts of the expenses of different lines should not only contain the engineering costs per mile, but the cost per vestry. It would be seen by the evidence given before the recent Tramway Committee, that in that respect there was an enormous difference in favour of Paris, in consequence of the unity of management and scientific administration existing in that capital in having only one authority to work through, and that a scientific authority acting with knowledge, instead of obstructive from ignorance and prejudice. He still thought that the granite tram, as adopted in Italy, possessed a prodigious advantage; but a well-laid asphalt might take its place, being only half the expense, and double the wear. The asphalt tram had the advantage over the granite tram, and indeed over the iron tramway, in the absence of joints, and when properly laid there were no jolts. Being, as it were, in one piece from end to end, there was little or no resistance, so that it was more favourable to the use of lighter locomotive machinery and carriages, than granite or iron. The tenacity of the Neuchatel asphalt, as displayed in Cheapside, with its traffic of sixteen thousand vehicles daily, was marvellous. It had been laid down about seven years, and had apparently lost little weight, and was only compressed by about one-third, and might have a wear as long as that in Paris, which was seventeen years. The wear of the ordinary granite trams at the East of London, with much less traffic, was stated to be about 1 inch a year. Much of the first asphalt roadway was defective in being wavy and undulating from being badly laid. He had been led to believe that the saving of tractive force on asphalt roads was about the same as that on granite tramways, or about one-half, as against common macadam roads, but he had later assurances that the saving on well-laid asphalt was fully two-thirds of the tractive force required on the common roads, enabling a proportionate saving of engine power on them. The obstacles that stood in the way of the application of the principle of the tramway were chiefly the divided jurisdiction of the roads and the want of science, some additional outlay, and no interest, created by a monopoly, such as was given by the iron tramway; the asphalt tramway being like the granite tramway in Northern Italy and this country, open to all private vehicles, which was, in reality, its recommendation. He had been at pains to ascertain the comparative wear of the road by the wheel and the horse, and he thought he could state it as a constant, that whilst the wear by the horse foot was as one, the wear by the wheel was as two.

Hence the tram he proposed would take away two-thirds of the common road wear. But it would have great importance in saving the wear of common carriages, as well as of locomotive machinery of all sorts. Locomotive machines were at present excessively heavy, as were carriages, to withstand the roughness of the roads. He did not mean to say that for roads of slight traffic, and for bye-ways, wheel tracks of cheaper construction than those he proposed might not be had. But a great object, as he conceived, for the attainment of economical transit was to get hardened wheel tracks open to all traffic.

Mr. Hopkins believed the time was not far distant when some mechanical power would be introduced on tramways. At present the only motive power at all complying with the requirements of the Board of Trade was steam and compressed air. Steam engines, made by Messrs. Merryweather, were running in Paris at the present moment; steam engines were also running in Brussels. Mr. Hughes had also succeeded in producing an engine which had given great satisfaction; and he had likewise seen an engine by Mr. Perrett which had considerable merit, but it had not been brought before the committee of the House of Commons. Mr. Scott Moncrieff's engine, worked by compressed air, had been running successfully at Glasgow; and M. Mékarski's compressed-air engine in Paris had worked admirably. They worked generally with a pressure of 4 atmospheres, and could run easily at 20 miles an hour, stopping within a short distance. In ascending gradients the action was perfect; the engine was stopped purposely, in the middle of an incline, about 1 in 20, and then ran down and ascended it again. The authorities were labouring under great disadvantages with regard to charging the cylinders, because they had only temporary engines for compressing the air.

Mr. Souttar, in reply upon the discussion, said, with regard to the complaint that his Paper contained no estimates, in the first place he had felt that estimates were to some extent misleading, and in the second place he had written a chapter on the subject, but had eliminated it as the Paper was getting so long. He regretted, however, he had not mentioned that a tramway would cost practically the same whatever system was adopted, and that it was a question of condition and not of system. In every well-constructed tramway there were three constant quantities, the concrete, the paving, and the rails, making more than three-fourths of the total expenditure, the remaining fraction being represented by the longitudinal bearing, fastener, &c. Comparing tramways with timber bearings together, the cost would be practically the same, or a little more where cross sleepers were used instead of tie-rods, and comparing these with tramways having iron bearings the latter would naturally be more costly. In Mr. Kincaid's system, with chairs 3 feet apart, the cost was, at the present price of iron, about the same as that of timber. The longitudinal bearing for the Manchester tramway was in the proportion to a timber bearing of 256 lbs. of cast iron to 6 lineal feet, by 6 inches by 4, of timber, with an allowance for cross sleepers and fastenings, the ratio being practically as 3 to 1. Mr. Lynde had stated that "the cost of this system varied from about £2,000 to £2,300 per mile, according to the weight of metal and depth of paving used." The remark illustrated what the Author had said about the misleading nature of estimates. For, taking the amount of metal required for the work, at market prices it would be found that the margin could only cover the labour of excavating, laying the line, and reinstating old paving. The estimate neither included concrete under the tramway nor paving, and the rail was only 40 lbs. to the yard, instead of from 50 lbs. to 60 lbs., as usually adopted. Mr. Beloe had fairly set down the price of a properly constructed tramway at £4,500 per mile, and with this price Mr. Lynde's system would appear to contrast most favourably; the fact being, however, that Mr. Beloe gave the price of a complete tramway, whilst Mr. Lynde gave the price of half a tramway. It could not be too clearly understood that the cost of a tramway was only slightly affected by the particular system under which it was laid, but materially by the weight of rail and quality of paving and concrete that the circumstances rendered advisable. Mr. Fowler's preference for a rail supported on a series of hard points, instead of on a continuous bearing, seemed incomprehensible, as well as his preference for iron over steel. Mr. Cowper's remark, that the grinding of the rails caused by grit or sand was better resisted by steel than by soft iron, was justified by experience. Mr. Fowler was under a misconception with regard to the rail which the Author had introduced. There was no space between the fastenings, the timber was the extreme width of the rail, and a little piece was gouged out into which the fastener sank. The sinking of the pavement on the Glasgow tramways, noticed by Mr. Beloe, was probably due to the fact that an unnecessary quantity of sand, 2 inches, was laid under the paving, and not to any failure on the part of the bituminous concrete. The tramway described by Mr. Rapier would be useful as a means of reducing the friction of heavy vehicles,

E 2

travelling at a slow pace, just as rows of flat stones were useful for that purpose. There were, however, points in the system which would render it unsuitable under ordinary circumstances, where a quick, rattling motion had to be endured; and there was nothing in its design calculated to diminish the cost of repairs, as compared with other tramways. Mr. Lawford disagreed with the conclusions on the subject of asphalt, and quoted an instance of asphalting in London. The piece referred to was done under the Author's superintendence, and he would therefore gladly defend it; but the fact mentioned, that it had been found necessary to put stone on each side of the rails, spoke for itself. Mr. Lawford said he should like to see a street tramway laid for £1,500 per mile, and then gave details of a tramway he had laid for less than £1,400 per mile. Of course a tramway could only be laid at the price mentioned under exceptionally favourable circumstances, and in the lightest possible manner. Mr. Perrett would find that "the immediate cause of the rapid loosening of the spiked rail from the sleeper" was the breaking of the spikes at the neck. Perhaps the construction of the car had something to do with this; but the Author thought it would generally happen when the rail became so worn that the wheel flange could touch the bottom of the groove. Mr. Perrett had contrasted some of the arguments in favour of a combined engine with some of the arguments in favour of a detached. For the former he claimed adhesion, handiness, and steering capacity. There could be no doubt that the combined engine was superior in the matter of adhesion. On the second point, the detached engine would be made handier to work than the combined engine in everything except shunting. On the question of steering there was little to say. Steering gear would complicate the car, and would be useless at night. It was questionable if the power of steering would be of any practical value. In dealing with repairs, Mr. Perrett had misunderstood the Author. In saying that a slight accident would cause £800 to lie idle, an accident to the car was meant, not to the engine. Whilst the Author felt that the question might be still more fully tested with advantage, he thought that every day showed more clearly that the detached engine was the tramway engine of the future. On the question of pneumatic cars, whilst recognising the difficulties in the way, the Author was scarcely so hopeless as some of the speakers. He was sorry that Mr. Scott Moncrieff had found it impossible to be present at the discussion, especially as he believed an arrangement had been concluded which would enable the method to be fairly tested in the course of the next year.

Mr. STEPHENSON, President, had hoped that more distinct information would have been elicited in regard to a better class of engine. The improvement of the rail would take place in the course of time. Some years ago he had occasion to examine the details of one of Mr. Grantham's engines, and he was strongly of opinion at the time that a separate or detached engine would be the best. He had carefully watched the progress of the engines, and although he was not prepared to give the cost of working, the more he had gone into the subject the more satisfied he was that a detached engine would ultimately come into use. He had no interest in any of the engines, and his opinion was, therefore, an unbiassed one. Mr. Longridge had objected to the detached engine on the ground that it had only its own weight to deal with for adhesion; but if he had looked at the matter more closely he would have seen that a detached engine could be made to take certainly half the weight of the carriage. It might be placed in the middle of two carriages, one-half of each carriage resting upon it, by a joint devised for the purpose. He was not prepared to admit that the old stock could be guaranteed for the proposed new tramways. He was glad that the subject of tramways had been discussed; and every one would desire that the sufferings of the horses might be relieved, even if the pockets of the shareholders were not filled to the extent they were at present.

Mr. DEACON remarked, through the Secretary, that for many years he had given attention to the subject of street tramways. Before making any recommendation with respect to the proposed reconstruction of the existing lines in Liverpool, he had visited all the more important tramways in this country and many of those on the Continent, and had studied the available literature on the subject. He had endeavoured to approach the question with a mind unbiassed by railway practice, or by the particular forms of street tramway which had in some degree grown out of that practice. His investigations had been completed with a strong conviction that no existing system of laying street tramways was entirely suited to the exigencies of the irregularly built and crowded streets of the principal cities and towns of this country. He thought inventors had not apprehended the true nature of the difficulties to be overcome before municipal authorities and the owners of ordinary vehicles could fairly be expected to approve of tramways. The inconvenience to ordinary vehicles, caused by cars having no power to move aside, was very great, and though not inevitable in a mechanical sense, it must be admitted as a necessary evil when street tramways were allowed at all, for nothing but confusion would arise if ordinary vehicles had the power to cause heavy tramway cars to leave the rails. But the evils of street tramways were due not only to the inevitable tramway car, but to the existence of the permanent way. This permanent way involved, for each line of tramway, four longitudinal joints between materials of different hardness. It was well known to be impossible, in the ordinary mode of paving, to prevent the formation of a groove wherever a longitudinal joint existed, even when the materials on both sides of the joint were the same. It was still less possible when the materials were of different natures. If, however, a course of setts were sawn in halves parallel with the street, and the setts were so bedded that the sawn joint remained close, the bearing surface of the setts was not reduced and no greater wear took place at the joints than elsewhere. Again, if near the line of such a joint the upper edges of adjacent setts touched each other at the transverse joints, there would be more bearing surface at and near the longitudinal joint than elsewhere, the intensity of pressure from traffic would be reduced, and instead of a groove forming, the wear would be actually slower than elsewhere. Having applied the same principle to the courses of setts immediately adjoining tramway rails, his expectations had been completely realised, after seventeen months' trial, under the most severe conditions.

During the reconstruction of the tramways in Liverpool the streets in which they were laid were being repaved and provided with new foundations from curb to curb. The vehicular traffic was entirely suspended, the old foundation was removed, and a bed of Portland cement concrete was laid and finished with a perfectly smooth surface, which was allowed to stand for ten days or more before the paving was commenced. Directly upon this the longitudinal sleepers rested. The rails were held down by bolts passing through the sleepers to plates beneath the concrete at every 3 feet, and these bolts could be tightened at openings in the sides of the sleepers. The setts next the rail were of durable stones, and were carefully dressed in such a manner that, unlike the other setts which were bedded upon ½ inch of sand, they rested firmly upon the concrete, while their edges touched the edges of the rails, and their sides near the rails touched, or nearly touched each other. Being laid alternately, and accurately gauged in all dimensions, they could be drawn and replaced with similar setts without disturbing the surrounding pavement. The joints of all the setts were filled with gravel from ¼ to ⅜ inch in diameter, among which a mixture of boiling pitch and creosote oil was poured.

It was generally known that in streets of moderate traffic the wear of a tramway rail, caused by the tram-cars, was insignificant in comparison with that due to the ordinary traffic. In the rail now in general use, 4 inches wide, a breadth of $1\frac{7}{8}$ inch was covered by the tread of the wheel, $1\frac{1}{4}$ inch being occupied by the groove, while the remaining width of $\frac{7}{8}$ inch was only useful for strength and as a guard for the flange of the wheel and the pavement of the horse track; but this extra metal gave only lateral strength, which was not required, while the whole surface, whether superfluous or not, was constantly being worn down by the ordinary traffic. It was therefore obviously important to make the rail as narrow as possible. A reduction of width would also lessen the danger to horses, and the incentive which the drivers of ordinary vehicles felt to occupy the rails, and thus wear them and the adjoining pavement unduly. If the groove were placed in the centre of the rail and the tread on both sides, not only would the pressure be better distributed, but the whole surface might be utilised, and with the same total width of tread the width of the rail might be reduced from 4 inches to less than $3\frac{1}{8}$ inches. Where, therefore, as in the case of street tramways, a groove was desirable, it was difficult to understand why it had never been placed in the centre. Mr. Souttar had referred to the central groove which Mr. Deacon had adopted, but had not stated the reasons for its adoption, though he had expressed fears that the friction would be greater, owing to there being no escape for mud or gravel; that the tendency of cars to run off on curves would be greater; and that the centre flanges on the car wheels would be weaker and more liable to chip off than the side flanges. The mud difficulty was common to all grooved rails. In the side-grooved rail, if there was enough mud to be pressed out, part escaped on the free side, part under the tread of the wheel. In this case it had twice as far to travel before it was liberated from the rail as in that of the central groove, where it all passed beneath the two half treads; so that for the same quantity of mud the two cases were almost similar. It was usual to remove mud periodically by an instrument designed for the purpose, and in order to avoid friction due to the squeezing out of mud during the intervals there was no objection to the groove being made deeper than usual. The Author of the Paper had given no reasons for his belief that the cars would run off the line more readily because the grooves were central; and as the flanges of the wheels were not altered in depth there was no mechanical reason why they should do so. The Author thought a side flange would be stronger than a central flange; but this was opposed to the known conditions of strength in projecting portions of castings. In cast-iron wheels the central flange with fillets on both sides would certainly be stronger than the side flange with a fillet only on one side; while any method adopted in the case of the side flange, to prevent it from becoming brittle by too deep chilling, was available in the case of the central flange.

In straight lines the central groove might with advantage be reduced in width. The flanges of tramway wheels were generally only $\frac{1}{2}$ inch wide, while the groove of the rail was more than $1\frac{1}{4}$ inch. He believed that great extra friction, due to transverse motion of the car, resulted from this; but the wide groove was stated to be necessary to hold mud. This might be a good reason for deepening the groove, but it could not, he submitted, be a good reason for widening it. Some allowance must be made for defective gauging of wheels and rails, but his own observations had led him to believe that $\frac{3}{4}$ inch for the width of a groove was ample. With such a central groove a rail $2\frac{1}{2}$ inches wide would have greater bearing surface than the present rails 4 inches wide.

Among the most expensive parts of a tramway to maintain were the points. Their chief cause of weakness arose from the want of sufficient area of tread when a wheel approached the point and bore upon its narrow surface only. This surface was rapidly worn down, and the wheel, on coming in contact with the tread of the rail beyond the point, had to mount on to it, and thus produced the inclined plane noticeable in all tramway points after a short period of use. The central groove and flange with the double tread obviously removed this difficulty. In Liverpool he had, unfortunately, had to consider the fact that the side-flanged wheels on the old lines must at first run upon the reconstructed portions also, and the width of the rail had therefore only been reduced from 4 inches to $3\frac{1}{4}$ inches.[1] For rails of the usual width the recessed dog-hook fastenings used by the Author had obvious advantages over the projecting dog-hook fastenings; but if used with the narrower rails, which he thought desirable, they would involve a greater reduction of the base of the rail and of the width of the sleeper than was consistent with stability. Another objection to such comparatively light

[1] Since this was written a length of about 1,000 yards of the most recently constructed tramway has been opened to traffic in Liverpool. The side-flanged wheels are now running in a perfectly satisfactory manner on the central-grooved rails, as well as upon the old side-grooved rails; but these wheels are being rapidly replaced with central-flanged wheels which, until the lines are entirely reconstructed, will also run on both kinds of rail.—G. F. D., Aug. 4, 1877.

fastenings was their greater number and consequent interference with the pavement before they could be reached.

Mr. H. Hughes observed, through the Secretary, that the locomotive designed by his firm had been tried against a compressed-air engine at Glasgow. The former engine had two cylinders, each 6 inches in diameter, with a length of stroke of 12 inches; the average pressure in the cylinders being 50 lbs. per square inch; the distance run was 31 miles; the time occupied in the run five hours and one quarter, and the speed 6 miles an hour. The compressed-air engine had two steam cylinders for pumping, each also 6 inches in diameter with a length of stroke of 14 inches. The air was compressed to 350 lbs. per square inch; the average working pressure was 50 lbs. per square inch. The distance run was 12 miles, and the speed 6 miles an hour. The steam engine was nine hours in compressing the air.

He thought the reason why some engineers were favourable to an engine placed in a car was, that they underestimated the power required. It had been found that the weight of a well-constructed locomotive engine, with all proper appliances, and to be safe for a tramway journey, without taking in fuel or water, would be 6 tons, a sufficient weight for adhesion. But if such an engine were placed in the car, the total weight on the four wheels would be 10 tons, a load too great for many tramway rails. The separate locomotive was a simpler way of distributing the weights on the rails, and of extending the wheel base without diminishing the facility of passing round curves. Moreover, in all cars containing their own engines which had yet been designed, the wheels were not coupled, thus dispensing with the merit to which their inventor laid claim.

Mr. A. O. Schenk remarked, through the Secretary, that in trying to find out the soundest mode of construction for the permanent way of street tramways, the probable substitution of mechanical for animal power, at no remote date, should be prominently kept in view. If this were effected, any defects in existing arrangements would be intensified, when the traction was obtained by the adhesion due to a concentrated load on two or more pairs of wheels. Under these conditions, the system, in which the rail was a mere bar laid flat, dependent for its stability on the permanence of the connections that united it with its continuous longitudinal support, must give way to a mode of construction better adapted to the new method of traction. In this arrangement the rails, under the action of passing loads, tended to slide upon the upper surface of the timber, but were resisted by the fastenings, these being thrown into direct shear, in the course of time, and under the frequent repetition of this action worked loose. If this was the case now, what might be expected when a thrust of considerable magnitude was exerted along the rail, dependent on the weight on the driving wheels and the state of the rails? Further, the longitudinals had little lateral stiffness; and when it was borne in mind that heavy vehicles came on and went off at all angles, it would be seen that the paving adjoining the rails stood a poor chance of maintaining its position, being constantly under the action of severe shocks. The breadth, too, of the longitudinal being limited to 4 inches or thereabouts, the load was distributed over a small area. This also tended to shorten the life of the road. The system known as "Barker's," in which the longitudinals were of iron, possessed no advantage over wood in this respect, and, being of a harder material, would be more injurious to the foundation; while it also appeared to have disadvantages peculiar to itself—such as the impossibility of getting a uniform bearing between rough surfaces of wrought and cast iron over a continuous length, and the want of surface in the cotters which secured the rail to the support. It would seem, then, that the system which would be permanent must be one in which the above-mentioned defects were avoided or overcome. Mr. Beloe suggested that a good road might be made by a rail of common bar-iron section attached to cast-iron chairs, fixed in their turn to cross sleepers. Such an arrangement had been devised by him some months ago. To this plan the following advantages were attached:—(1) A rail was used which had vertical stability enough to carry the load without continuous sleepers. (2) The load was distributed through a broad-based chair over an area which was limited by considerations of expense. (3) A rail could be taken out and replaced without interfering with a single paving sett. (4) No iron fastenings were employed, and the evils of corrosion and enlargement of holes were avoided. (5) Less smooth iron was exposed on the surface of the street than in any other system. (6) The form of rail was adapted to the formation of points and crossings, and was well fitted for bending round curves limited in radius by the width and angles of streets. (7) It compared favourably in first cost with the best of existing systems, while in subsequent maintenance a considerable reduction might be looked for.