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Preliminary planning for a new tube railway across London †

by

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Discussion

Mr H. D. Morgan (Partner, Sir William Halcrow & Partners, Consulting Engineers) said that the cost of an underground railway system was very high, but the value of such a system to a city was in fact considerably higher than its direct commercial value measured in terms of receipts from fares. An underground railway in a city was just as important as its sewerage system or fire service; it was essential. In any city with a population approaching one million an underground railway was needed, whether the authorities wished to provide it or not. Efforts were sometimes made to avoid providing it. For example, at Caracas in Venezuela, which had been essentially an old Spanish colonial town, the Government had used bulldozers to knock down buildings and make great straight avenues to enable motor-cars to move faster, but the result had been a great many more motor-cars and the roads were as jammed up as before; so the authorities had had to think again about the provision of underground railways. The cost of such railways was extremely high, but it was impossible to do without them.

92. The cost, however, was the real difficulty. The average citizen was compelled to live some distance from his place of employment and to travel there and back on at least 5 days a week. If he lived, say, 12 miles from Charing Cross, the cost was about £40 a year. From nearer the centre, say from Hammersmith or Clapham, it was about £22 a year. Since 75% of the population of Britain earned £12 a week or less, that represented a large proportion of income, yet it was not sufficient to pay for the construction of underground railways. That was the problem. The streets of London were congested with parked cars, and Mr Morgan was convinced that the vast majority of them belonged to people who lived near the underground system but insisted on coming into the centre by road. To take legal proceedings against the drivers would require many hundreds more magistrates! He had been told that 87½% of these cars were subsidized to some extent by the employers of those who used them. That pointed to the need for the development of underground railways on a bigger scale than at present.

93. Mr Morgan mentioned an underground railway which had been proposed in Calcutta at one time which would have required a passenger density of 10 persons/sq. m or 1/sq. ft. He had suggested that 0·5 person/sq. ft was a more realistic figure and he was shocked to learn that the figure went up to 0·6 person/sq. ft at the worst periods in London.

94. Mr Morgan had made an estimate (based on experience with the precast concrete lining used for the main-line tunnels at Potters Bar) of the saving in prime cost by the use of a new type of concrete lining in place of the cast-iron lining. It appeared that the tunnelling costs could be reduced by about 50% by using such a lining for a plain tunnel; it would not be so advantageous with the number of stations on the proposed tube line, and the cost of the whole scheme would not be reduced in that proportion. For the running tunnels, however, such a reduction in cost should be possible. This type of lining, however, might have other advantages. Fig. 8 showed the reduction in

† Proc. Instn civ. Engrs, vol. 12, p. 19 (Jan. 1959).

air resistance obtained by having a smooth surface. When the train was pushing a column of air in front of it, the resulting pressure drove air through the annulus to the back part of the train at a much higher velocity. The cast-iron lining provided a rough surface which must result in a higher pressure. The chain-dotted lines in Fig. 8 showed the reduction with a smooth surface, but had account been taken of the presence of cables and brackets? Many tube tunnels bristled with cables and brackets, which had to be there, and that might detract from the advantage of the smooth surface.

95. Mr Morgan showed a slide indicating those services at Oxford Circus which had so far been traced—there must be many more of them—which gave an idea of the problems that the engineer had to face. In addition there were all the dead services, of which there were no records at all. The smaller services varied in depth between 1 ft 6 in. and 12 ft 6 in. The big middle-level sewer of the L.C.C. was approximately 56 ft below the surface. Then there were the column bases and basements of surrounding buildings, which might require underpinning. Many plans in the past had been shattered by Peter Robinson's because the basements of that building projected almost to the pavement line.

96. In comparison with about 90 miles of twin track in tunnel on the London Underground system, the L.C.C. had 400 miles of sewers in the London area, many of which were larger than the tube tunnels. In addition, there were about 2,000 miles of local sewers. A strict check had to be made on the positions of all such services before any work involving the driving of new tunnels could be undertaken.

Mr C. E. Dunton (Chief Civil Engineer, London Transport Executive) said that the commonly heard plea for more and better roads in London frequently stemmed from emotion rather than reason. The people of Britain were enjoying the first flush of being a motor-car-owning society and the freedom of the open road was a libertarian concept, while the sort of control and management which had to be exercised in the running of a public transport system was easily magnified by the loose-tongued into "totalitarianism".

98. On the plane of reason, however, it was obvious that in a city such as London a really efficient public transport system was essential. It would be unfortunate if the effect of providing improved roads was to deny capital for public transport. If roads and car-parks in Central London were made adequate for all those who now claimed need of them, that area would almost cease to be a traffic objective.

99. Other cities throughout the world had reversed the 1920–40 trend of replacing rail-borne public transport vehicles by unconfined road vehicles. In West Berlin and Hamburg road-level trams were being replaced by shallow underground railways. In Russia, Moscow had been given good roads and a good underground railway system; both were necessary. In London, the objective, as outlined by the Paper, was very limited. It was to effect a distribution of the traffic pressure from the parts of greatest congestion, by joining up an uncompleted system of tube railways built more than 50 years ago by private and competing companies.

100. Mr Dunton thought that the most modern ideas of town planning for Central London (and highway planning in general) must tend to more roundabouts and introduce multi-plane traffic circulation, but this could result in greater inconvenience to the public by separating the pedestrian farther from his bus, train, or car park.

101. The "hybrid" pneumatic-tired underground train might one day provide a solution. It could negotiate gradients of perhaps up to 1 in 8 and so could provide much closer access to the long-distance-travel services. It would, however, require a different planning approach from that now prevalent in London. It would require a large capital expenditure and there would be no immediate profit, but it would perhaps in the long run preserve expensively produced buildings from the deterioration in value which they must otherwise inevitably suffer through traffic strangulation and congestion —a feature which was already causing concern in the United States.

102. In the meantime, London Transport hoped to get the necessary capital—a

modest sum in relation to the vast developments in London—to construct an essential deep tube railway.

Mr R. M. Robbins (Secretary, London Transport Executive) said that the Victoria Line differed from other big civil engineering works in one very important respect. The site of a big bridge or a dam or a road tunnel could normally be selected with some regard for engineering considerations; but a new underground railway had to be exactly at the right spot from the traffic point of view, and the engineers had to overcome every obstacle in order to put it there.

104. The initial planning, before the engineers were called in at all, had to be done in the greatest detail and had to be right. There had to be an absolutely firm and solid "pre-engineering" assessment of what the traffic required. With so much short-distance traffic moving about the metropolis, sometimes for 2 or 3 miles or even less, siting an underground station even only 600 yards from where it ought to be could lead to a very serious waste of money. Once a wrong selection had been made it could never be put right.

105. It was broadly true that the need for a line across London with the general alignment of that now proposed had been recognized for a good many years. What London lacked was a line running north-east to south-west across the heart of the West End. The existing network of underground railways had met the requirements of the Edwardian decade very well, because they had been focused on two points: one in the City (the Bank) and the other (Charing Cross) in the West End. Since then, however, London's whole commercial and business "centre of gravity" had changed, and there was now a need for the other arm of the X of which one was formed by the Bakerloo Line.

106. It was necessary to know how much the line would be used, and so it had been essential to make the most detailed estimates possible of the likely traffic on the line and through the interchanges. The traffic on such a line would consist in part of passengers diverted from other underground lines, and in the case in point largely from the Piccadilly Line. There would be those who had formerly used the bus services but preferred the new line. In the outer sector there would be passengers who would find it more direct than the British Railways route. There would be passengers who before had not travelled at all or who had not previously made use of public transport. So far as the passengers likely to be drawn from other forms of public transport were concerned, it was possible to make estimates which seemed to be reasonably satisfactory, but the traffic new to public transport was exceedingly difficult to assess.

107. New traffic could arise either because the line provided a new facility for getting from one point to another without changing, or because, the distance being shorter, the time occupied by the journey would be less, and also, incidentally, the cost might be less. For the Victoria Line certain comparisons could be made. The journey from Victoria to Oxford Circus, which at present took 17 min with one interchange, would take 8 min by the Victoria Line. From Victoria to King's Cross, a journey made by large numbers of people, now took 20 min with two interchanges and a great deal of luck. By the Victoria Line it would take 13 min. It was possible, therefore, looking at those figures, to make reasonable estimates of how much new traffic would be attracted to the line if it were built.

108. Above all, however, there was the most important social fact that it would have a very material effect on the congestion of the streets above. The amount of private-car traffic which would be diverted to the line would be very significant indeed. It would also be possible to take a few buses off the streets. If the bus milage was reduced by 3,000,000 miles/year, that was equivalent to 2,000 bus journeys on an ordinary weekday.

109. The Victoria Line would have a potential carrying capacity of 32,000 passengers/hour in one direction through the central section. Some people would travel in the other direction, say 8,000, making 40,000/hour. To move 32,000 people/hour by private car, assuming 1½ passenger/car (which was the correct figure for London rush hours),

would require a motor-road capacity of fourteen traffic lanes for one direction, on the assumption of 1,500 cars/hour/lane, the figure normally taken in America.

110. It was still exceedingly difficult to make, from the figures available, any coherent picture of traffic in London; i.e. to know where the vehicles in the streets had come from and were going to. It was to be hoped that the new Traffic Engineering Branch of the Ministry of Transport and the traffic engineers that the local authorities were proposing to use, would study this problem, because the planning of the Victoria Line or of any other was severely hindered by lack of knowledge of origins and destinations.

111. The London Transport Executive felt that in view of the number of people likely to be diverted and the public advantage which would result from the relief of the streets they ought to be allowed to get on with the Victoria line and that the money ought to be provided.

Mr A. H. Cantrell (Chief Civil Engineer, British Railways, Southern Region), said that the Southern Region of British Railways suffered greatly from having to carry very large numbers of people on a system which had been designed many years ago for far less traffic. The type of study described by the Author was essential to the design of a new tube, especially in London. In spite of the efforts which had been made to secure a staggering of office hours, the tendency had been in the opposite direction. In 1938 the Southern Railway brought to London during the rush period of $1\frac{1}{2}$–$1\frac{3}{4}$ hours in the morning 236,000 people. Today during the morning rush period of only 1 hour they brought 357,000 people, an increase of 51%. He hoped that in planning the new tube it had been realized that the position was likely to become worse. It was no use taking as a basis the exact figures which were available today.

113. The Southern Region had built two double-decker eight-car trains but, although more people could be carried, they took longer at the stations, so that there was no real increase in the numbers that could be carried in a given time. Platforms had therefore been lengthened on some routes to take ten-car instead of eight-car trains. The ten-car trains carried more passengers, but once more it had been found that it took longer at the stations to load them. It also took longer for a ten-car train to pass a signal—a considerable factor when trains were following one another with the shortest possible interval. The extra time taken for a ten-car compared with an eight-car train to pass a signal was $1\frac{1}{2}$ sec at 50 m.p.h. Traffic was so intense that the average speed was less than 50 m.p.h. At 40 m.p.h. the extra time was 2 sec, and at 20 m.p.h. it was 3·8 sec. If the train was stopped at a signal and started again, then, assuming that the average speed while passing the signal was 10 m.p.h., it took 7·7 sec. That had a cumulative effect on the following trains.

114. In § 61 it was stated that "The minimum vertical curve used in tube railway work should be at least 1 mile rad." Some years ago on the Southern Region a flyover had been built where, working to a speed of 45 m.p.h., the vertical curve at the top of the flyover was of 10,000 ft radius, which agreed closely with the Author's figure, but the bottom of the curve, where there was a virtual dip, had been based on twice that figure, 20,000 ft. The curve at the crest had been chosen for passenger comfort and the larger radius at the bottom of the dip to safeguard the springs of a fully loaded train. Had the Author considered that sort of thing ?

Mr A. W. Manser (Chief Mechanical Engineer, London Transport Executive) said that the rush period was a critical factor in the handling of traffic by London Transport. The evening peak was, for London Transport, concentrated to a far greater degree than the morning peak. Station-stop time was a highly critical matter when running a really intensive service down to a 90-sec headway. The construction of the Victoria Line would relieve the supersaturation at many points on the underground system during the morning and evening rush periods.

116. It had not always been recognized that excess escalator provision was uneconomic. There were stations where it was possible for passengers to pour down on to the platforms at a far greater rate than that at which the trains could carry them away.

In that respect, although they had been criticized for it in some quarters, the Toronto Transit Commission may have been wise in restricting the size of their escalators.

117. The idea of using articulated stock had had to be abandoned in view of the decision that 12 ft was the right size for the tunnel. The limitations on loading-gauge made it impracticable to get a deep enough structure to ensure a long enough spacing between bogie centres to give a satisfactory train lay-out. To obtain the desired symmetrical train design which would uncouple into two equal portions required (with the sort of station length that it was practicable to consider) 10 cars, whereas it could be done with the conventional arrangement with 8 cars.

118. Mr Manser was sure that the hump profile did not really achieve a 20% saving. It had the reverse effect if, owing to extended station stop times, a train was checked at the home signal, when the kinetic energy was dissipated in braking and more energy had to be expended in climbing the hill to the station when the signal cleared.

119. For the rubber-tired train project it was necessary to have a tunnel much larger than 12 ft dia. To accommodate a train of the kind proposed in Paris, would need a tunnel diameter of about 17 ft. Some of the advantages claimed for such an arrangement were more theoretical than real. One of them was smooth riding, but Mr Manser's experience had been that the riding had been inferior to that obtained on good long-welded track. The acceleration was obtained only at great cost in plant to back up the tremendous surge of power required. Acceleration was also limited by considerations of passenger comfort. The claim of lightness of construction was made for this stock, but it was not borne out in fact. There was a very real objection to rubber-tired stock if it were required to run out into the open. One of the reasons for the London Transport Executive not going further with the idea was that all their lines ran out into the open, and in conditions of snow and ice the high rate of braking claimed as one of the advantages would not be obtained.

Mr F. G. Maxwell (Operating Manager (Railways), London Transport Executive) said that initially the train service proposed for the Victoria Line was of the order of 30 eight-car trains/hour, trains of the same passenger capacity and general design as the new silver Piccadilly Line trains. With 30 eight-car trains/hour the capacity would be almost as great as on the Northern Line with 37 seven-car trains/hour. They would be made up of two identical four-car units, capable of uncoupling into four-car trains for use in off-peak periods. A service of 20 four-car trains/hour would be provided from Victoria in off-peak periods, with some reduction at King's Cross or, if not there, certainly at Seven Sisters.

121. To ascertain the volume and direction of probable traffic, detailed calculations had been made for each passenger subway. The figures of overall flow had first been assessed from other known cases of similar types of traffic where the total annual movement and the maximum movement in the peak 15 min was known. At Oxford Circus today about 5,800 passengers came into the station in the peak 15 min in the evening, and 41 million used the station in the course of a year. Taking the size of the stairways or subways along which these passengers moved today a peak-quarter-hour/annual ratio was obtained which was then applied to the new station subways. Thirty completely different flows of traffic had been examined at Oxford Circus station alone, and Mr Maxwell was convinced that the subways, designed so as to produce movement in one direction only, would carry the traffic which was going to come.

122. Experience of cross-platform interchange was already available at Hammersmith, Mile End, and Finchley Road. There would be five such stations on the Victoria Line: Wood Street, Finsbury Park, Highbury, Euston, and Oxford Circus. Oxford Circus was designed as a cut-off for the present difficult exchange at Charing Cross and to relieve the hard-pressed section of the District Line between Victoria and Charing Cross. At Euston the form of interchange described by the Author was to enable West End passengers from Golders Green or High Barnet to take the first southbound train irrespective of whether it was bound for the City or the West End.

123. At Highbury, the cross-platform interchange was to assist Eastern Region

passengers from the Great Northern system when electrified, to avoid the heavily congested portion of the Eastern Region between Finsbury Park and King's Cross, by riding through to Highbury and changing to the Victoria Line to reach the West End; this would discourage them from changing on to the overloaded Piccadilly Line at Finsbury Park.

124. If it were possible to have a station with a platform loop, giving a third platform road, when there was heavy traffic a train could be run into one platform and while it was doing its station-stop duties the following train could be run into an adjoining platform to halve the station-stop time, which was the limiting factor in line capacity. Unfortunately there was no room available to put a three-platform or loop station anywhere on the new tube line where it would be of any use. A third platform would be invaluable at King's Cross. A loop would, however, be used at Seven Sisters, where in the north-east direction a second train would be able to come in to the island platform when another train was on the other side.

Dr A. W. T. Daniel (Lecturer in Civil Engineering, Queen Mary College, University of London) said it had been estimated that the new tube would not earn enough revenue to cover interest on capital, but if it was instrumental, as had been predicted, in easing the flow of traffic through the streets it would be saving London as a whole the money estimated to be lost as a result of traffic congestion. Expenditure on street improvement might also be reduced. It seemed a pity, therefore, that the construction of the tube could not go forward with the help of some arrangement by which the interested parties who would actually make savings could contribute capital at a nominal rate of interest.

126. In § 17 it was stated that in addition to the aerial survey it had taken twelve men about a year to check the plans on the ground. Why had this to be done and what proportion in man-hours and cost had this ground work borne to the whole of the survey work? It was stated in § 16 that for some areas the 1/2,500 ordnance maps were enlarged to 1 in. to 88 ft. That was 2½ times.

127. Had a final decision been taken on the diameter of the tunnel? He hoped that the diameter would be sufficient to take stock of District Line capacity, because it looked as though this would be required. That would mean that connexions to existing tubes could not be used and Northumberland Park would have to be a depot for all repairs. Had consideration been given to a possible connexion with the District Line at Victoria so that the Acton depot could be used? This would be a great opportunity, and extra capacity would probably be essential, so why limit the line to eight-coach trains? Trains of greater length, ten-coach or even twelve-coach, should be considered despite difficulties.

128. He suggested that uni-directional flow of people through the carriages should be tried, by making certain doors "Entrance", and the others "Exit", and marking the platforms clearly at the places opposite which the "Entrance" doors would stop. By this means station times would be reduced, which was the key to the capacity of a tube railway.

129. Had any consideration been given to driverless trains, as suggested for Moscow underground, and what effect would they have on operating costs?

Mr W. H. Ward (Deputy Head, Soil Mechanics Division, Building Research Station, D.S.I.R.) said that the public was interested in comfort as well as convenience in travelling. Convenience was not merely the province of the carriage designer but embraced many aspects which concerned the basic civil engineering plan. Mr Ward found the stuffiness, the strong, dusty winds, and the noise of the underground system sufficiently unpleasant to make him choose forms of travel which were often less convenient.

131. The Author had hinted at the possibility of the tunnel lining incorporating a bed for the track and of the use of smooth concrete linings of a somewhat larger diameter than usual, on grounds of economy in cost and lower tractive effort. Had he considered the effect of these changes in tunnel construction on the comfort of the passengers? At present most of the ventilation appeared to be carried out by the trains

in passing along the tunnels. If so, less air resistance on the trains would reduce the rate of ventilation. The present high temperature in the existing system indicated a need for more adequate ventilation; but the high winds were unpleasant, particularly when charged with dust, and more attention might need to be given to the design and layout of station passages on this account, in addition to the logistics of passengers.

132. In several parts of the underground system the mean annual air temperature had risen at least 20°F above the normal ground temperature of about 50°F. Some of this increase in temperature came from the energy released by the trains and their occupants, but not all of it. Some recent observations which Mr Ward had made in the course of tunnelling through virgin ground 50 ft beneath built-up areas in the West End suggested that the ground temperature had risen about 12°F on account of the presence of the buildings on the surface. Had London Transport made a study of the heat balance problem, and could they suggest any way by which the rise in temperature could be limited to a reasonable level, other than by more ventilation ?

133. One other factor in this change might be the introduction of a smooth surface to the lining, and this would lead to an increase in the transmission of noise along the tunnels and, while some sound from a train approaching a station was a necessary danger warning, was not the present noise level high enough?

134. Some years ago London Transport had taken effective steps on certain routes to reduce the noise level within the trains by installing sound-absorbent barriers along the tunnels. His impression was that this improvement had been greatly appreciated by the public. If a concrete lining was going to be used, some basic reductions in noise levels within the trains might be achieved at small cost by providing, for example, a porous concrete finish, which might be given to the lining blocks at the time of casting, without the need to apply expensive additional finishes after erection of the lining. Similar ideas might be used in the stations to replace the hard renderings and the tiles, provided the dust problem could be overcome.

Mr H. G. Follenfant (New Works Engineer, London Transport Executive) thought the Paper had amply demonstrated that the planning of a large transportation project was mainly an engineering problem. The planning depended upon the closest collaboration throughout the undertaking of all those who had to operate the line and its equipment. Fundamental to the success of the plan was a full appreciation of all the practical aspects and it was the trained engineer who was best able to have that outlook and lead the way.

136. The Victoria line would be a route with one closed end and one open end. The major and most complicated works were, as the Author had shown, in the middle of the line, at Oxford Circus, Euston, and King's Cross, and those works would determine the overall programme of the line. Oxford Circus would probably be the key position. After the tunnels had been completed throughout would come the equipment, the laying of the track bed and the track, the signalling, the power-supply cables and so on. For that reason one of the first things to be done at the Northumberland Park depot was to establish an equipment depot and organize the equipment of the line from there.

137. The planning of the equipment and the liaison engineering planning of the line depended on the sort of organization which had existed in the Engineering Department of London Transport ever since the enlargement of the City & South London Line had been started in 1920.

138. Mr Follenfant mentioned a few of the technical improvements the L.T.E. were considering. Interior smoothness of tunnels had been mentioned in the discussion, and the Author had referred to the size and type of tunnel lining and had shown that a tube train in a tunnel of 12 ft 6 in. dia. would not have much greater air resistance than in the open. With the new types of concrete and iron linings, the types which were expanded against the clay the diameter would have to be 12 ft 6 in. in concrete and 12 ft 8 in. in iron, because being smooth they would be without the recesses of the conventional cast-iron lining into which bulky equipment such as signal relay boxes was

so conveniently fixed at present. The structure gauge required those sizes. At an early stage in the programme—Mr Follenfant would not like to be more explicit—they would like to try a mile of new-type lining to test its practicability and cost and rate of progress, where there was no heavy property overhead and where there was adequate clay cover.

139. A working party was studying improvements in the permanent way. Long-welded rails would be used without question. The general standard of track, however, had been developed over the years and had been satisfactory. Some chairs and fastenings now being renewed on tube lines had been in since 1906. All possible modifications to the standards were being considered.

140. All this planning which the Author had described was a painstaking procedure, and it could drag on. The Author must have been frustrated many times and have yearned for the impetus which would be given to the whole of the planning work by authorization.

Mr A. T. Wilford (Director of Research, London Transport Executive) said that the operational research work mentioned in the Paper, had been carried out by small teams consisting of technical representatives from the Engineering Departments, the Operating Department, and, occasionally, from the Medical Department, with certain members of the research staff attached. The team gave the technical background and facilitated the provision of observers, who were seconded from departments and worked temporarily on the job. It was necessary in nearly all these cases to plan surveys. The research staff, as a rule, carried out the preliminary survey, to find out the magnitude of the job, and, after taking statistical advice, the large survey was planned to get the maximum information with the minimum expenditure and manpower, and to a known degree of accuracy. Finally, the results were analysed and a report agreed by the team.

142. It not infrequently happened that the report confirmed something already known, but even then it gave a quantitative basis on which to continue the practice, and it would stop for a long time the question being asked again. In many other cases there were no data on which to form even subjective estimates, or there was a conflict of opinion.

143. For instance, the Author had mentioned that the new tube stock would not have a central pillar in the double doors. When the general investigation of doors had been started, certain trains had had double doors with a central pillar while others had had no central pillar. One school of thought believed that the central pillar divided the channels of boarding and alighting passengers and reduced station-stop times, while the other considered it a hindrance. The team had examined nine types of door, only some of which had a pillar; about 6,000 sets of observations had been made and 140,000 passenger movements had been studied. It had been found that under crush-loading conditions, but no others, the doors without a central pillar were about 10% faster than those with a central pillar.

144. Operational research had been of assistance in deciding to have stand-back space at double doors. The object was to try to give full access to the double door space, which was impeded by passengers who leaned against the screens on each side. In this instance there had been only one experimental car to work on, and it was always difficult to compare one experimental feature with a whole lot of standard ones. From the statistical point of view it was wrong to attempt it. The first investigation had given an inconclusive answer, because it had not been possible to get maximum loading of the experimental car. That trouble had been overcome by having the car transferred to the Northern Line and taking observations round about Christmas and the time of the after-Christmas sales, when travel on the Underground, particularly in the West End, was at a maximum. The car with stand-back space had been shown to be better than the standard cars and to give boarding and alighting rates about one-third faster than the standard cars. That one-third-faster rate could not reduce station stop time by that amount, because crush loadings did not exist the whole time; but it had been cal-

culated that the stand-back space was worth 1½ sec/station at busy stations during the peak.

145. The investigation of escalator accidents had been one of the most unrewarding jobs tackled by operational research. The number of accidents was very small, and yet not quite small enough to be regarded as random variations. The Author's suggestion that they might be due to the popularity of narrow high heels was one possible explanation, but it did not seem to be the full explanation. The explanation had not been found even now, but it seemed just possible that it might be due to the increasing age of the population at large.

146. The present efforts of the Operational Research Section were concerned with station-stop times and means of reducing them. As always, the real problem was to study movements of people. The new office blocks would provide additional problems. People's travel habits varied, and passengers did not always use a facility in the way expected, so that an investigation had no finality. Some of the plans which had to be made in connexion with the Victoria Line were irrevocable, or could be altered only at great cost. Although changes might seem intuitively to be right it was necessary to support them by quantitative data derived from operational research.

Mr W. Mainwaring-Burton spoke for a few minutes of his experiences during the construction of the Northern Line more than 55 years ago.

Mr E. W. Cuthbert (A Senior Engineer, Sir William Halcrow & Partners, Consulting Engineers) estimated that the construction of running tunnels of 14 ft 6 in. dia., compared with 12 ft 3 in. or 12 ft 6 in., would mean an increase in cost of 30–35%. For that extra expenditure the trains would have an increased capacity of 10%, but would the line capacity be increased by the same percentage? It would take longer to get the larger number of passengers in and out, and the headways might be a little greater than on a normal tube line. An increase in the cost of the running tunnels of 30–35% might sound considerable, but he estimated that it would represent only 5–7% on the total cost of the line, assuming the cost to be about £50 million.

149. During the past 4 years the Metropolitan Water Board had been constructing a tunnel, mainly in London clay but partly in Woolwich and Reading beds below the clay, 19 miles long, of which about 17 miles had been completed and nearly 16 miles had been lined with mass concrete segments of the expanding wedge type. The rings were 2 ft wide and the internal diameter varied, being 8 ft 7½ in. and 8 ft 10½ in. The segments were 6 in. and 7½ in. thick respectively. So far, 13 miles of 8 ft 7½ in. and 3 miles of 8 ft 10½ in. had been built. There was no bolting of the segments. Most of the line consisted of twelve equal tapered segments, six facing one way and six the other, so that the shield rams tightened the lining against the muck and there was no grouting.

150. Cost records showed that the cost of tunnel lined with the wedge-type lining was half that with the bolted reinforced concrete lining, of which about a mile had been built. There was also a short length lined with 9-ft-dia. cast iron, and the cost of this was 2·7 times that of the wedge-type lining. Experiments had been made with a small number of rings which had been built by expanding the wedge-type segments within high-tensile steel hoops, with the object of getting a ring which would stand up if bad ground was encountered and grouting was necessary, and where overbreak made the building of the normal expanding rings impracticable. On that slender basis he estimated that the modified wedge type, expanded in the high-tensile steel hoops, would give a cost of 1·5 against 1 for the normal wedge type.

151. In his opinion it would be reasonable to extrapolate those ratios to diameters of 12 ft to 14 ft 6 in., and the shields could be designed on much the same basis. A digger shield had been successfully used in a diameter less than 9 ft, loading on to a conveyor belt, and with that system a rate of progress of 350 ft/week had been maintained for many weeks. Where normal hand shields had been employed, with the men shovelling into the skips direct, progress had been 180 ft/week for a long period. The comparable rate of progress with bolted linings of the same diameter was 120 ft/week,

the difference being due to the need to bolt up the linings, so that the rings took longer to erect, and to grout them subsequently.

152. The Author had stated in § 71 that this type of lining might be suitable for water tunnels and had implied that it might be unsuitable for railway tunnels, but it would be no more liable to collapse if it were used for a railway than for water. There had been trouble in some places where the clay had been fissured and overbreak had occurred at the crown, so that the rings had had to be built with care and the space above stuffed. When the lining had been erected past the overbreak the remaining cavities had been grouted. This had produced a tunnel which should not collapse in service.

153. Doubt had been expressed about what would happen if water got down the joints between rings and softened the clay behind. If the joints were properly sealed there should be no trouble afterwards with seepage from the ground or leakage outwards whether the tunnel were used for water or railway.

154. In Fig. 3 there were shown long sections of tunnel which were flat or with a gradient of the order of 1 in 2,800. Could an artificial dip be produced in order that drainage facilities could be provided for those long lengths of tunnel? Pools were inevitable with gradients of that order and should be avoided.

155. Referring to § 71, Mr Cuthbert said that equipment such as cables and signals could be conveniently fixed to mass concrete wedge-type linings by bolts secured in holes drilled on site. Owing to the difficulty of aligning the segments to suit the superelevation required, it would not be practicable to incorporate the track bed with the segments, and it was suggested that an in-situ bed, reinforced longitudinally, would be required. Since the distance between tunnels was not restricted by the width of streets, there appeared to be no objection to constructing the tunnels generally with sufficient undisturbed ground between them for the wedge-type lining to be used safely. When it was essential for the tunnels to be close together, the first tunnel could be lined with the modified lining employing high-tensile-steel hoops to provide adequate stiffness. No new problem arose from the use of the wedge-type lining for pilot tunnels which were to be enlarged subsequently, since the rings would be dismantled one at a time as excavation for the larger tunnel proceeded. If such an enlargement had to be carried out after the new railway had been opened to traffic, each ring of wedge-type lining could be girdled by a high-tensile-steel hoop stressed by means of a jack as excavation proceeded, pending dismantling during track possessions.

156. In shield-driven tunnels with bolted linings the longitudinal joints were relatively weak in bending and the friction between adjacent rings might well contribute more to the strength of the tunnel as a whole than the bolts in the circumferential joints. Excavation alongside a shield driven tunnel lined with wedge type segments should therefore give little more difficulty than alongside one lined with bolted segments. Adequate timbering was necessary in both cases.

157. While there might be difficulties locally in connexion with foundations for high buildings if wedge-type lining were used, the additional cost should be far outweighed by the savings in employing such linings for 11 route miles of railway.

The following contributions were received in writing.

Mr B. W. Morton (Engineer Agent, Taylor Woodrow Construction Ltd) thought that in view of the high cost of the scheme it might be advisable to split the work into two phases. The first phase should include the more urgent Victoria–King's Cross section. This might entail additional work at Victoria, where a connexion with the District Line might be found essential; alternatively, additional headings there would allow the parking of several trains. Similar arrangements would also be required at King's Cross but in that case the additional headings could later be utilized for the extension to Highbury and beyond. A connexion to the Piccadilly Line at King's Cross should not present insurmountable difficulties to the engineers.

159. A further suggestion to cut down the time required for station stops would be

to have the seats back-to-back the full width of the coach, with a good distance between the rows, i.e. there should be about 6–8 ft between the people facing each other, while they would share the same back rest. Each such section would have a large set of double doors to allow quick access for large numbers and this would also increase the number of standing passengers which could be carried during rush hours. The doors could move horizontally to overlap at the space beside the seats or alternatively a new system of vertical opening doors should be possible. The latter might discourage people from holding the doors open to allow further passengers to enter at a time when the train should be moving off.

Mr T. T. Lambe (Partner, Messrs Rendel, Palmer & Tritton, Consulting Engineers) did not fully understand the Author's reference in § 27 to the possibility of increasing the schedule or terminal-to-terminal speed too much. Should this perhaps read maximum speed instead of schedule speed?

161. With regard to length of train, had consideration been given to making a radical increase in the length of the train such as, for example, increasing the number of cars from 8 to 16 and, where local conditions permitted, arranging for platform exits towards the centre with entrances at each end. These would have separate escalators from ground-level station entrances, 1,000 ft or more apart. This would admittedly be more expensive but it would enable traffic to be dealt with at crowded stations, such as Oxford Circus, which were already choked to capacity at the station mouths at the crush-hour.

162. The Author had referred to a slight reduction in the number of trains per hour with longer trains and, of course, it must be conceded that the distance between the end of one train and the front of the next would inevitably be reduced by about 440 feet if Mr Lambe's proposal were to be adopted.

163. However, with end-platform entrance, would not about 2 min start-to-start time-interval be necessary between trains to provide for even distribution over the length of the train? This would not be increased by entrances at each end for double-length platforms and passengers would occupy any excess time at their disposal by approaching the end most suitable for their exit.

164. Some increase in acceleration and retardation over those at present employed might be considered. Experiments on the Paris Metro had shown that it was a high rate of change of acceleration and retardation rather than the high rates themselves, which caused distress to passengers. A smooth rate of change of acceleration over a period of 2 sec was found to be satisfactory.

165. Might not such developments, in conjunction with some suitable form of automatic speed-control signalling, permit 45-sec intervals between the start of one train and the stop of the next? This would meet, to an appreciable extent, demands that arose under conditions of excessive station-stop times. Such delays could, in turn, be avoided by the provision of separate doors for entry and exit, commonly adopted for trams and buses in certain countries.

166. The additional expense of multiple station entrances would, of course, be very considerable but, as an alternative to widening streets, such as Regent Street and Piccadilly, or building overhead roads, would appear to be quite reasonable and might be taken into account when considering the capital expenditure involved as compared with a line capable of taking the same traffic more evenly distributed in time. The additional rolling stock, although expensive, should not in fact form a large proportion of the total capital expenditure and the maintenance cost per passenger carried might not be appreciably increased.

167. A point of great importance would appear to be the provision of adequate and attractive parking arrangements for cars and cycles at terminal stations. If large capital expenditure was to be incurred in providing station buildings and track area, it would appear sensible to incorporate in them really ample parking space for cars and also possibly buildings to accommodate offices and shopping centres in the modern style.

Mr C. T. Gardner (retired) recalled that proposals made before the turn of the century to build underground railways under the London parks had been rejected because of the possibility of damaging trees. Yet now, 60 years later, the need for the Victoria Line—although it would be unremunerative—had been recognized. How changed was the outlook!

169. Since passenger transport was a non-productive industry it would seem that the constantly rising wage bill must eventually mean that further developments or extensions would have to become a charge on users of transport elsewhere or on the non-using public. This was a problem of social economics outside the scope of the civil engineer.

170. The solution of the passenger transport difficulty seemed to have reached an *impasse*. The capacity of existing systems could not be increased. Lack of good facilities to outer London would compel denser occupation of the land nearer the centre; but this would bring its own traffic difficulties and was not a solution to the problem.

171. A city planner would find little difficulty in designing a lay-out of roads through which, for several years, traffic could pass freely; the engineer would guide him through the principal problems. But would it be done on an adequate scale soon enough?

172. Overhead railways had been eliminated because of their noise, but they had been designed before the days of pneumatic tires and internal combustion engines. Mr Gardner suggested that a partial solution could now be found in overhead rail- or road-ways (or the Stronach-Dutton combination), nearly soundless and without appreciable vibration, carried above existing roads, passing through buildings where convenient, and providing halt and transfer points under cover, using a portion of an existing building, if required.

173. Such overhead ways would permit moderately rapid transport: their first cost and their operation would be less than that of the tubes. The routes and methods could be changed to meet changes in demand, for they would not be inflexible, like a tube railway.

174. Mr Gardner quoted from Professor Levy's James Forrest Lecture, 1953: "Can civil engineering cope with the changing needs of society?" His answer was that "it must".

Mr G. W. C. Appleby (Charles Brand & Son, Ltd) writing as a Londoner who had just had his first ride on the Glasgow subway asked if the Author had given consideration to an adaptation of the method used in Glasgow for regulating passenger flow. The passengers entered the train by one door and left by another. There was no bunching at the doors by short-distance travellers who felt that they might not reach an exit if they moved "down the car".

176. The station platforms were marked to show where the entrance doors would be when a train stopped, so for an eight-car train people would cluster in groups opposite each car. Those leaving the train would alight on to a relatively clear platform.

Mr W. J. F. Ray (Resident Engineer (for Messrs Binnie, Deacon, & Gourley) Oyo Water Supply Scheme, Western Nigeria) observed that, although all travellers from Victoria to the West End would support a proposal to construct an additional tube railway such as that described, it was difficult to justify the estimated cost of about £50 million on purely economic grounds. The importance of making a start, however modest, could hardly be overemphasized, for once work had commenced and the interest of the public aroused it was more likely that adequate funds to ensure completion would be made available. Had consideration been given to the possibility of carrying out the work in stages to reduce the firm financial commitment at any one time to a smaller amount.

178. Construction of the line between Victoria and Oxford Circus could well be undertaken as a first stage, possibly operating initially as a shuttle service over a single track, and the construction of the new booking hall at Victoria could be deferred until extension of the line generated a sufficient volume of traffic. It would be necessary for

the new line to be interconnected with the Bakerloo Line tracks at Oxford Circus to provide access for the rolling stock. The tube diameter and rolling stock would then, of necessity, have to be similar to that of the Bakerloo Line, but it appeared to be the Author's opinion that in any case that was the most practical diameter for the proposed line.

179. The rate of construction of the lengths north would be dependent on the finance available but every extension should result in an increase in the number of passengers carried. Operation of the line immediately after construction of each section would result in an immediate return on the capital invested.

180. In all probability the bulk of the traffic would be generated in the central area. Had any consideration been given to surfacing the line north of Finsbury Park and operating over the existing tracks of the Tottenham and Hampstead Joint Railway to reduce the capital cost of the Scheme?

The Author, in reply, said that the question of train resistance in tunnels, referred to by Mr Morgan (§ 94) was a subject worthy of more research. The chain-dotted lines in Fig. 8 were based on some experiments made on models in Budapest University. The full lines were deduced from the train resistance curves, Fig. 7. As far as it could be ascertained from the report of the tests, cables had been included in the models of both smooth and ribbed tunnels.

182. Mr Morgan mentioned in § 94 the possible saving of 50% of the cost of tunnelling by using concrete lining instead of the usual bolted type of cast iron. If this were done in all running tunnels the saving in cost would be only some 15% of the total notional estimated cost of the project, given in § 4 as £50 million excluding rolling stock. Nevertheless, the large amount of money involved made the use of concrete tunnel lining worth serious consideration.

183. Mr Cantrell asked a question about vertical curves (§ 114). In tube railway work the changes of gradient were more frequent than on the main lines, especially where the hump profile was adopted, Fig. 7; in the design of vertical curves, therefore, at least as much consideration had to be given to smooth running and passenger comfort as to the important effect of the vertical curve on the rolling stock.

184. Regarding the question asked by Mr Daniel (§ 126) it had been necessary to make a physical check on all features that were shown on the Parliamentary plans. Also levels had been taken for preparing the longitudinal section. The corrected Ordnance sheets had saved a tremendous amount of time and labour in this work. Before the tunnels could be driven a normal ground survey had to be made and the centre-line of tunnels calculated.

185. More than one contributor to the discussion had suggested that a connexion to the District Line should be made (§§ 127, 158). This, of course, was not impossible, but how much was it worth? To purchase easements for deep tunnels was one thing; to buy property for a subsurface railway was quite another, and there was also the cost of diverting many large sewers and other services to be taken into account. The new tube would have a connexion with the Piccadilly Line at Finsbury Park as shown on Fig. 14 and this line already had connexions with the District and Northern Lines. If the line was built for larger than normal size tube rolling stock it would follow that as well as greatly increasing the constructional costs for the larger diameter tunnel, the cross-platform interchange at Oxford Circus, Euston, Highbury, and Finsbury Park would have to to be forfeited which would be out of the question. Furthermore since the railway would be deeper, in order to clear some of the existing tunnels, see § 64, the escalators would cost more to build and to maintain, and the journey time for passengers would be longer. It was considered, therefore, that the advantages of building a tube for larger rolling stock, with a 10% greater carrying capacity, were outweighed by the disadvantages given above.

186. Another point raised by more than one contributor dealt with the arrangement of seats and the suggestion of uni-directional flow of people within the trains (§§ 128, 180). As mentioned in the Paper, the bogies in the tube stock projected above

the floor of the cars, thus restricting both the seating arrangements and the positioning of the doors. It was a fact that there were at least two tube systems in other cities that had adopted the uni-directional passenger flow in the trains. The advantages of this system were more obvious, but there were disadvantages:—

(*a*) The trains on any one line must have the same door arrangement. On the existing tube system this was not so.

(*b*) A passenger getting into a crowded train last, perhaps with luggage, was at a great disadvantage if he wished to get out before the majority of other passengers.

(*c*) An equal number of doors for boarding and alighting was satisfactory only when the flows were equally balanced. As the flows at most stations were not balanced delay was bound to occur.

(*d*) The training of passengers was not easy and the more complex the system, the less the people would use the tubes.

187. In answer to the question by Mr Daniel (§129), there was no technical reason why the tube trains should not be automatically operated and be apparently driverless. Trains of this type had been operated on the Post Office Railway in London for many years and were now in use on some underground railways abroad. One railway man would have to be on each train in case of emergency. It was not possible to state the operational saving for there would have to be additional equipment, entailing increase in capital and maintenance costs. In addition, a few more platform staff would be required for some stations. The Author hoped that driverless trains would soon be tried on London's Underground.

188. Mr Ward was not quite correct when he said the ventilation of the existing tube was carried out mainly by the movement of the trains (§ 131). From tests it could be shown that trains did create a back and forward air movement, but by far the greatest change of air for heat removal in the existing tubes was forced mechanical ventilation. At present fans were moving 5,000,000 cu. ft/min. It was true, however, that if larger tunnels were adopted, air speeds caused by the trains would be reduced. On the new line it was proposed to install fans in the working shafts between stations. The fans would be designed so that they could be reversed, operating as extract fans in the summer and pressure fans in the winter.

189. At stations the working shafts would remain to act as relief shafts. That was now London Transport's standard practice in order to reduce the air speeds mainly created by the trains. For passenger comfort it was desirable to have some air movement at stations. The designs of all new stations had been examined to make sure that the air speeds would not exceed about 15 m.p.h. London Transport had made a study of the heat balance problem (§ 132) but as in most subjects there was still room for more investigation. Apart from ventilation, other methods for reducing the tube temperature included water circulation, refrigeration, humidification, and regenerative braking.

190. Mr Cuthbert was quite correct in his assumption that it was undesirable because of drainage to have long lengths of level or nearly level tube tunnels (§ 154). It was hoped that when the results of the boreholes were known it would be possible to alter the particular gradient to which he referred. As Mr Cuthbert knew London Transport must not build the new tube tunnels within a prescribed distance from the new Water Board tunnel, and at the same time it was desirable to keep the tube tunnels within the thickness of the London Clay.

191. It had been the general principle to build new tube railways in stages, as suggested by Mr Morton (§ 158) and Mr Ray (§ 183). Frequently when this had been done, however, there had been a certain amount of abortive expenditure, and the Victoria Line would be no exception. In fact, if the line were built from Victoria to King's Cross as a stage, the abortive expenditure involved would run into six figures.

192. Referring to the question (§ 160) raised by Mr Lambe, on § 27 of the Paper, a train service with the minimum possible headway would clear the greatest number of passengers from their originating station in the least time, but the speed of the trains would be so low that such a service would be unacceptable to passengers. Going to the

other extreme, a very fast service could be run provided that the headway was sufficiently wide, which would enable the few passengers whom it would then be possible to accommodate to reach their destinations in a comparatively short time. This service would be inadequate to deal with the rush hour traffic, for which a reasonably close headway was essential. Therefore, when choosing a train service for a particular line a compromise between these two extremes had to be made.

193. The double-ended stations referred to by Mr Lambe (§ 161) are undoubtedly ideal, for they gave one set of platforms the largest passenger catchment area. Also the capital and revenue cost of providing and manning additional banks of escalators together with booking facilities was very large, and unless it could be shown that the additional entrance was going to attract a very large number of additional passengers it was not a sound financial proposition. The stations on the new tube had been examined from this angle and only at one station, Seven Sisters, had it been considered worth while to provide a double-ended station. The principal booking hall for that station would be under Tottenham High Road at a busy road junction. The other one would be adjoining Seven Sisters main-line station. Thus two separate traffic objectives would be served.

194. With reference to Mr Lambe's question in § 165, the speed control signalling installed on the Piccadilly Line enabled 90-sec train intervals to be maintained even though the 30-sec station stop was exceeded by as much as 18 sec. Alternatively, if station stops could be kept down to the 30 sec, a 73-sec train interval could be achieved.

195. To answer Mr Ray's question in § 185, London Transport had considered more than one scheme for bringing the new tube to the surface north of Finsbury Park. The saving in capital cost would be slight and the passenger facilities very poor. For instance, the layout at South Tottenham would necessitate a walk of about 100 yd from the station entrance to the platforms and the station entrance would not be at the road junction, the focal point for road transport. Moreover, by re-routing this section, a satisfactory site for a rolling stock depot could not be provided.

196. Finally, the question was raised by several contributors, on the justification for building a new tube line, that it was not likely to make sufficient profit to repay its capital cost. London Transport had a fares policy common to both buses and tubes. In practice the section with the smaller capital and operating costs, viz., the buses, makes the profit, and the tubes tended to show a loss. As the cost of building tube railways had greatly increased in recent years, it was unlikely that it could be anticipated that it would make a profit. As it would not be suggested that an existing line should be closed because it did not pay, the anticipated deficit would appear an insufficient reason for not building a new one. Especially as in this case the line would not only assist passengers using it but help to operate most of the existing lines more efficiently over their most crowded sections.