G.L.C. Combinations accept a network description, carry out the calculations automatically and provide an output of the recommended signal settings in a form which should help the traffic engineer to appreciate which parts of his network are most critical. The example table (Fig. 2) gives an idea of the layout of the final output table of G.L.C. Combinations— it directs attention to the high predicted delay on link 7.

Under-saturated junctions. The major assumption of the Combination method, that links are independent of each other, is in practice acceptable for junctions more than 70 per cent saturated with traffic. If a particular set of traffic signals is fully saturated, the traffic flow at the entry of one link and at the exit of another is completely controlled by the green period so that the same traffic conditions are correctly reflected in the simulation of both links. If the junction is under-saturated, the simulation of one link may assume that the traffic passes early in the green period, whereas the simulation of the other link may assume that the same traffic passes late in the green period. For example, in Fig. 3, if the road between traffic signals A and B, which are both heavily saturated, has an intermediate signal, e.g., pedestrian crossing, at B, the Combination method simulations would be carried out separately for links AB and BC. On link AB the platoon of traffic from A would pass through the signal at B with delay for the wide range of offsets of timing between A and B. Similarly, delay would not vary much with offset on link BC, and the two links in combination would show little delay for any offset between A and C. In reality there may only be one offset between A and C for which a platoon would pass reasonably unhindered and suffer low delay.

In this case it is to omit junction B from the computation, and fit it into the established progress afterwards, or to operate it at a simple fraction of the network cycle time. Similarly, in a two-way road the optimisation of arrangements for crossing traffic or crossing pedestrians requires a 'cumulative link' to be built into the network joining the two directions of traffic on the road. Facilities for dummy links were available in the original Combination method, but easier to use in G.L.C. Combinations and the necessity for them is largely avoided by not

tlipulating. Watkins has shown that the problem is only important if two or more adjacent intervals are under-saturated.

Program organisation

Error checking. G.L.C. Combinations goes to a considerable length to check errors in the input data. Over-saturated junctions, incompletely specified signal cycles, irreducible networks and the like are detected. The checks, are also, detect over 80 per cent of clerical and punching errors. The program is regularly used in accordance with a simple guide by traffic engineers without computer training.

Recycling. Traffic engineers are frequently interested in determining the performance of a network under a number of different conditions. G.L.C. Combinations allows up to six different values of cycle time and stop penalty to be specified in one computer run. Also the network description need not refer to all the links simulated so that different alternative networks may be studied without having to repeat input information of basic data on individual links.

Printing flexibility. On some occasions the traffic engineer simply wants an output table like that shown in Fig. 2, giving the signal settings which he is to use. On other occasions he may wish to consider the impact of engineering changes on traffic behaviour and will require delay/offset tables for individual links. G.L.C. Combinations allows the amount of printing to be specified for each link or for each stage of the calculation.

CONCLUSION

The development of TRAFFY and G.L.C. Combinations have followed roughly parallel courses so that both programs are now available for regular use by traffic engineers. G.L.C. Combinations has been used on a number of schemes in London, in particular for the calculation of the basic plans for the West London Experiment, on IBM 360 Fortrace deck and Simple for the calculation of the basic plans for the West London Experiment, on IBM 360 Fortrace deck and Simple. The city of Stoke-on-Trent.

In this article a town centre road network is considered as a single mechanism and an attempt is made to explain the workings of the mechanism is described. This work was carried out as part of the technical investigations associated with the preparation of a Traffic and Transport Plan for Ipswich Borough.

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The town centre road network of a town such as Ipswich with a population of 120,000 is a complex mechanism. Simple measurements were made at the evening peak period and the data obtained were used to explain the workings of the mechanism of the road network.

Briefly, journey time measurements were made by the moving observer method at peak periods over a considerable number of days and the concentration was determined from a set of aerial photographs taken at the peak period. The network consisted of over 100 uni-directional links. Very few links consisted of more than one traffic lane and all were comparatively very short. The average length of a link was approximately 0.01 mile.

Figures 1 and 2 show how the mechanism operated. Figure 1 shows how the mean journey speed of vehicles varies with the number of vehicles on the network and Fig. 2 shows how the capacity of the network in vehicle miles per hour varies with the mean speed of vehicles.

Fig 1 (left), Relationship between mean journey speed and number of vehicles on a town centre network.

Fig 2 (below), Relationship between mean journey speed of vehicles and total vehicle mileage on network.

November 1969
At the present peak period the mean journey speed of vehicles was 7.4 mph and the number of vehicles on the network is approximately 900. Figure 2 shows the surprising results. The maximum capacity of the network expressed in vehicles per hour is shown to occur at a mean journey speed of 9.4 miles per hour and at a speed approaching 3 miles per hour might have been expected. If this represented an unstable condition, then jam conditions would be expected to occur every day. If it represents a stable condition, then it may be conjectured that as the mean journey speed drops below 9.4 miles per hour the capacity of the network falls and the necessary number of vehicles to produce jam conditions are unable to get on to the network. The present speed of 7.4 miles per hour may therefore represent the minimum practical mean journey speed of the existing network.

Before publication of the relevant data at present it is not possible to prove or disprove this hypothesis. However, it does provide a better explanation of why traffic has been brought to a standstill as was predicted some years ago and it explains why traffic flow which has been continuously recorded on one link of the network has not increased over the past four years. Although the computer of Ipswich which travels by cars may have found the work journey in the town centre taking progressively longer over the past years, it may be conjectured that they have spent a similar period on the network, but longer waiting to get on to the network. The queues have grown longer in the car parks and on the roundabout approaching the town centre.

So far, the only check on the results has been made by comparing the predicted mean journey speed at the off-peak period with the measured value. Aerial photographs taken at an off-peak period were used to provide the number of vehicles on the network. One circuit of the network has been made by the moving observer method to determine the off-peak mean journey speed of vehicles. These provisional results gave 420 vehicles on the network and a mean journey speed of 13 miles per hour. From Fig. 1 the mean journey speed when 420 vehicles are on the network is shown to be 14.2 miles per hour, i.e., an over-estimate of 1.2 miles per hour. The predicted figures are based upon peak period conditions when virtually no waiting or loading takes place. The waiting and loading which takes place at the off-peak period (i.e., off-peak period) could have the effect of reducing the theoretical mean journey speed of the network by about 1 mile per hour.

Practical applications
In addition to journey time measurements, queuing time measurements were also made. Isolated links were drawn for various points of origin including all access points to the network from public car parks. Journey times on the network were found to vary from about 5 to 10 minutes at the present peak period. Considerations of total flow across the town centre, which is located in a patch point formed by two natural features, give an average journey time on the network of 8.5 minutes.

As an example of the application of the information, the case of a new public car park in the town centre may be considered. It is assumed that drivers would be permitted to attempt to enter or leave at any time including the peak period. The location would indicate the average time spent by the driver in the car park at the present peak period. Assuming this to be 9 minutes. If the new car park was to accommodate 100 vehicles at a maximum rate of one car per exit every 7 seconds (any payment having been made on entry) then two results may be considered.

(1) If the cars are so located that the cars can gain direct access to the network, then in 9 minutes the following additional cars will be on the network:

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Cars Added</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>154 cars</td>
</tr>
</tbody>
</table>

By reference to Fig. 1, this indicates that the mean journey speed would drop by approximately 1 mile/h to 6.4 mile/h. A correction may be made for the time spent on the network at the lower speed, but this has an insignificant effect. It will be appreciated that the rate of discharge of cars from car park exits is of more significance than the capacity of the roads. The duration of maximum discharge from a car park exit has an effect on the demand and the coincidence of the periods when different car parks discharge cars is of great significance.

(2) If the cars are so located that the cars cannot easily gain access to the network, then it may be assumed that the network was subject to congestion at a mean journey speed of 7.4 miles per hour and that 900 vehicles spend approximately 8.5 minutes on the network. In this case, all the additional car park discharged 500 vehicles at the peak period it could be predicted that the duration of the peak period would be extended by:

500 × 8.5 minutes = approximate 5 minutes

Queueing would occur in the new car park and conditions in other car parks, would give access to the network would become worse; complaints could be expected from irate motorists, 500 of whom could be expected to spend the extra 5 minutes waiting to enter the network.

Any improvements in conditions on radial roads on the approach to the town centre which permit more vehicles to gain access to the town centre must be viewed with caution. The working of the mechanism of the network shows the effect that this could have on mean journey speed.

If the mechanism of the network can be altered by the provision of more traffic signals, the linking of traffic signals or the provision of area control by computer, then it may be conjectured that the capacity of the network may be increased. After such an improvement the mean journey speed at which maximum capacity occurs and the number of vehicles on the network at this speed could be determined. A system of area control might be designed to maintain optimum conditions. To ensure such conditions it would probably be necessary to control at the peak periods all points of access to the network including car park exits, radial roads, and minor links. This might result in quite large numbers of traffic light signals operating at peak periods. Practically, the system might be adjusted by repeating the survey methods already developed after the initial installation of area control and determining the new optimum operating conditions. That part of the computer program associated with network conditions generally might be adjusted and the whole process repeated until optimum conditions were shown to have been reached without further alteration.

Although the consideration of the network as a mechanism cannot replace the consideration of the individual parts to the system and the effect that changes in one part of the network will have on the network as a whole, it does enable the traffic engineer to consider the effects of changes in one part of the network on a quantitative basis. In Ipswich it shows that without physical improvement the network cannot accept more vehicles at the peak periods. It gives a measure of how long the peak period would be extended if the number of vehicles leaving the town on the network in the peak period were to be increased substantially, demonstrating that those vehicles gain direct access to the network so as to increase the number on the network at any one time. This information is particularly applicable to the preparation of the Traffic and Transport Plan (M.T. Cirelat 1/68) for Ipswich.

Data collection
In order to measure journey times and queuing times over very short links an electronic measuring device was developed based upon the circuits provided by the Road Research Laboratory. The mechanical inductive unit in the original design was replaced by a capacitor and a Hall effect unit powered by eight high-performance U2 dry batteries (Fig. 5). The prototype was developed and made operational by a local firm of instrument makers at comparatively low cost. A team of three observers went out every Tuesday, Thursday and Friday between 5.30 and 6.45 p.m. over a period of several months to collect the journey times and queuing time information. The overall length of the circuit is 12.25 miles, but the circuit necessary to cover every link and every junction, taking all legal means, was 16 miles in length. Only two circuits had been completed at the time that this article was prepared. Five circuits have now been completed at the peak period and the results confirm the facts reported in this article.

The aerial photographs of the peak period were taken by an aerial survey company. The photographs of the off-peak period were found to exist in the office as a result of the network from radial roads. Only one set of each was available, the correlation between the two sets was taken as an indication of the reliability of the results when groups of links were considered together.

Data analysis
Figures 4 and 5 show the histograms of journey speed against the number of vehicles on the links. The journey times were used to calculate the journey speed on each link. The matrix diagram and the scatter diagrams were drawn for the purpose of determining the number of vehicles on each link. The vehicles on a link were assumed to be travelling at the journey speed of the link. Although this assumption was not designed to exist at any particular time. Although, in fact, vehicles move from link to link, it was assumed that a constant number remained on each link or groups of links.

November 1969

Fig. 4 (above). Histogram of journey speeds of vehicles on town centre network.

Fig. 5 (below). Histogram of peak period journey speeds of vehicles on town centre network.
The concentration of vehicles on groups of links with like journey speeds was calculated for each class interval of journey speed from the information contained in Figs. 4 and 6. Figure 6 shows these values of concentration plotted against journey speed. A straight line relationship of journey speed (the continuous line in Fig. 6) was drawn, and adjustments were made manually until the values of concentration read off the graph matched the smoothed concentration of the network at various journey speeds. This network relationship was used to show the relationship between journey speed and concentration on the network for journey speeds between 5 and 60 miles per hour.

In order to determine the effect of changing more or less vehicles on the network certain assumptions had to be made, as follows:

1. Groups of links with like journey speeds at the present peak period will be those journey speeds under different conditions of network loading.
2. The relative density of vehicles in the groups of links with like journey speeds will remain constant under different conditions of network loading.
3. The journey speed and journey concentration of the groups of links under one condition of network loading can be represented by a straight line relationship with journey speed on a logarithmic scale.
4. The journey speed and journey concentration of any one group of links can be calculated from journey speed and journey concentration of other groups of links.

The assumptions were checked for the off-peak period when the data are analysed. Assumption 2 is shown to be valid for the off-peak period and off-peak periods, whereas Assumptions 1 and 3 are valid for the on-peak period only. The relationship between journey speed and journey concentration on the network between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

1. The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

(a) The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

(b) The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

(c) The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

(d) The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

(e) The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

(f) The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

(g) The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

(h) The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

(i) The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

(j) The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

(k) The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

(l) The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

(m) The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

(n) The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

(o) The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

(p) The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

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(r) The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

(s) The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

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(u) The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

(v) The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

(w) The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

(x) The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

(y) The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows:

(z) The relationship between journey speed and journey concentration on the network for journey speeds between 5 and 60 miles per hour is not in fact valid there are several possible explanations, as follows: