Technical Meeting of the Institution

held at

The Institution of Electrical Engineers

Wednesday, November 7th, 1962

The President (Mr. R. A. GREEN) in the chair

The minutes of the Technical Meeting held on October 5th, 1962 were read and approved.

The President introduced and welcomed to the meeting Messrs. B. L. Wijkman, G. Knall, and C. Insulander (Members) who were present for the first time since their election to membership.

The President then invited Mr. G. Knall to read his Paper entitled "Signalling Developments on the Swedish Railways".

Signalling Developments on the Swedish Railways

By GÖSTA KNALL (Member)*

INTRODUCTION

To get a proper understanding of the development of Swedish railway signalling, it is necessary first to have some idea of the structure and operating conditions of the railway network. Compared with the situation in Britain, for instance, our lines are very long and the traffic density is comparatively low. We have as much as 14,800 kilometres of line for a population of only 7½ million within an area of 450,000 sq. km. This is without comparison the highest track-kilometrage per head of population in Europe. Double track is laid only in a small part of the network—chiefly between the main cities Stockholm-Gothenburg and Stockholm-Malmö—and covers a distance of 1100 track kilometres. Of our total number of some 1,200 stations, barely more than one hundred have more than three main tracks. The speed of trains on the double track lines is 100-130 km. per hour and on other main lines 90-100 km. per hour. The extent of the railway network and the traffic load in ton-kilometres are shown in fig. 1.

In 1960 passenger traffic accounted for 81 million train kilometres, goods traffic for 37 million, and the iron ore line for 2 million. The total quantity of freight in the same year was 27 million tons, excluding Lapland ore which amounted to 17 million tons.

Competition from air and road traffic has rendered a fairly large part of the network unprofitable, and sections which carry little traffic are being closed down. The network remaining after the retrenchments is likely to be around 9,000 kilometres.

Private railway construction has been very extensive in Sweden, and at the beginning of the century two-thirds of the railways were privately owned. At the time of the decision to nationalise, in 1939, rather more than half the railways were in private hands. Today there are few private

* *Swedish State Railways.*

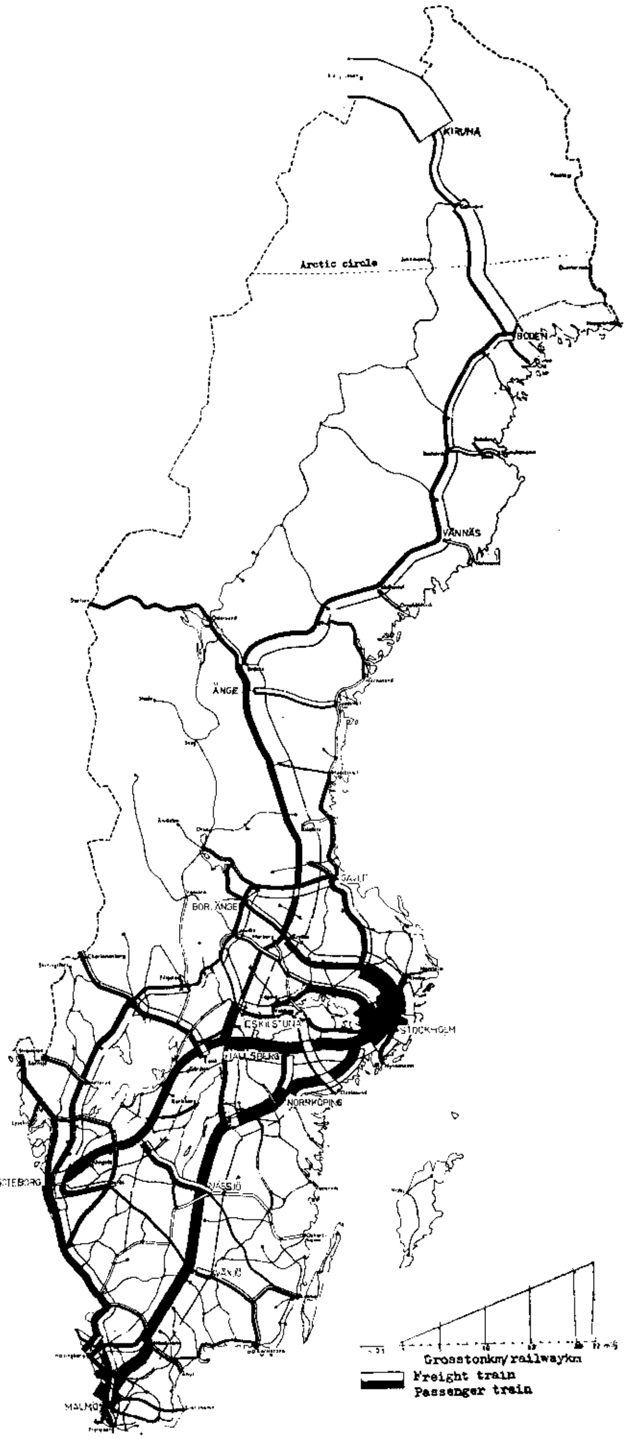


Fig. 1 Map showing utilisation of the Swedish Railways

railways left, the largest being the Trafik AB Grängesberg-Oxelösund railway (TGOJ) with its 300 kilometres of line.

The electrification of the Swedish railways is now almost completed. The length of electrified line is 7,360 kilometres, corresponding to 50 per cent of the total length of line. Of the total traffic, measured in gross ton kilometres, 93 per cent is hauled by electric traction. The operating voltage on the contact line network is 16,000 V. and the frequency is 16 2/3 c/s. The railways obtain electric power from the public three-phase distribution network and produce their own single-phase requirements by the use of motor generators. These motor generators are placed in converter stations along the track at intervals of about 100 kilometres.

The State Railways (SJ) employ at present about 60,000 persons on rail and road operation. The staff has been considerably reduced through various modernisation measures in the past few years. Recent rises in wages, however, have been very heavy, and still more radical action is necessary to cover the deficit, which in 1961 was 50 million kronor.

DEVELOPMENTS DURING THE '50s

This period was characterised by the change-over from the earlier mechanical or electromechanical equipment to purely electrical relay interlockings. Our earlier signalling technique was closely linked to the German system, and the older equipment in particular was partially imported from Germany. The stations on our main lines had mechanical signalboxes of the conventional type, and track circuits were used only at the larger yards which had electromechanical interlockings. The block system was based on telephone messages between the stations, except on a few stretches where automatic block signals were employed.

The problem now was to plan the development so as to cut costs while increasing safety. A statistical analysis was made of actual and threatened accidents. It was found that 75 per cent of all mishaps which could have been prevented by safety measures were traceable to errors committed by train despatchers—particularly through defective route inspection but also through failure to advise train departures. Only 4 per cent were due to drivers passing a stop signal. To get a complete picture, the seriousness of accidents should somehow be taken into consideration. Apart from this, however, the investigation showed the most urgent task to be to equip our stations with track circuits in the main tracks and—having in mind especially the consequences of a mistake—in the first place the stations with through-traffic. For the same reason automatic block signalling deserves high priority. It was decided, however, that Automatic Train Control, which was included among the items discussed, should be left in abeyance for the time being.

The construction of signalling plant in Sweden during the past ten years has been largely on these lines—that is, we have concentrated on the building of complete relay interlockings with track circuits at small stations or overtaking points and automatic blocks on the main lines. There were also practical reasons for this. It is technically very much easier to build relay interlockings at small than at very large stations; for the latter the SJ, like other railway administrations, has long been feeling its way towards the most suitable type of plant. Furthermore the construction of a large plant involves many other organisational difficulties such as the reconstruction of yards.

The best way of effecting a major overall saving of manpower, while employing a minimum of additional staff on construction and planning, has proved to be the installation of complete interlocking plants at small stations and on lines, automatically protected level crossings, and finally the remote-control of stations.

Salaries and wages have long been at a comparatively high level in Sweden, and public undertakings have found difficulty in competing for manpower with private enterprises. For this reason the Swedish Railways have had to have recourse to far-reaching automatisation measures. A considerable effort has therefore been expended on the introduction of C.T.C., primarily on single track lines where the duties of the local staff, apart from train control, are very limited. The development may perhaps best be expressed in figures. In 1952 we had 2 relay interlockings, in 1962 we have 148. In 1952 we had automatic blocks on 87 km. of single track and 288 km. of double track, in 1962 on 862 and 882 km., respectively. C.T.C. today

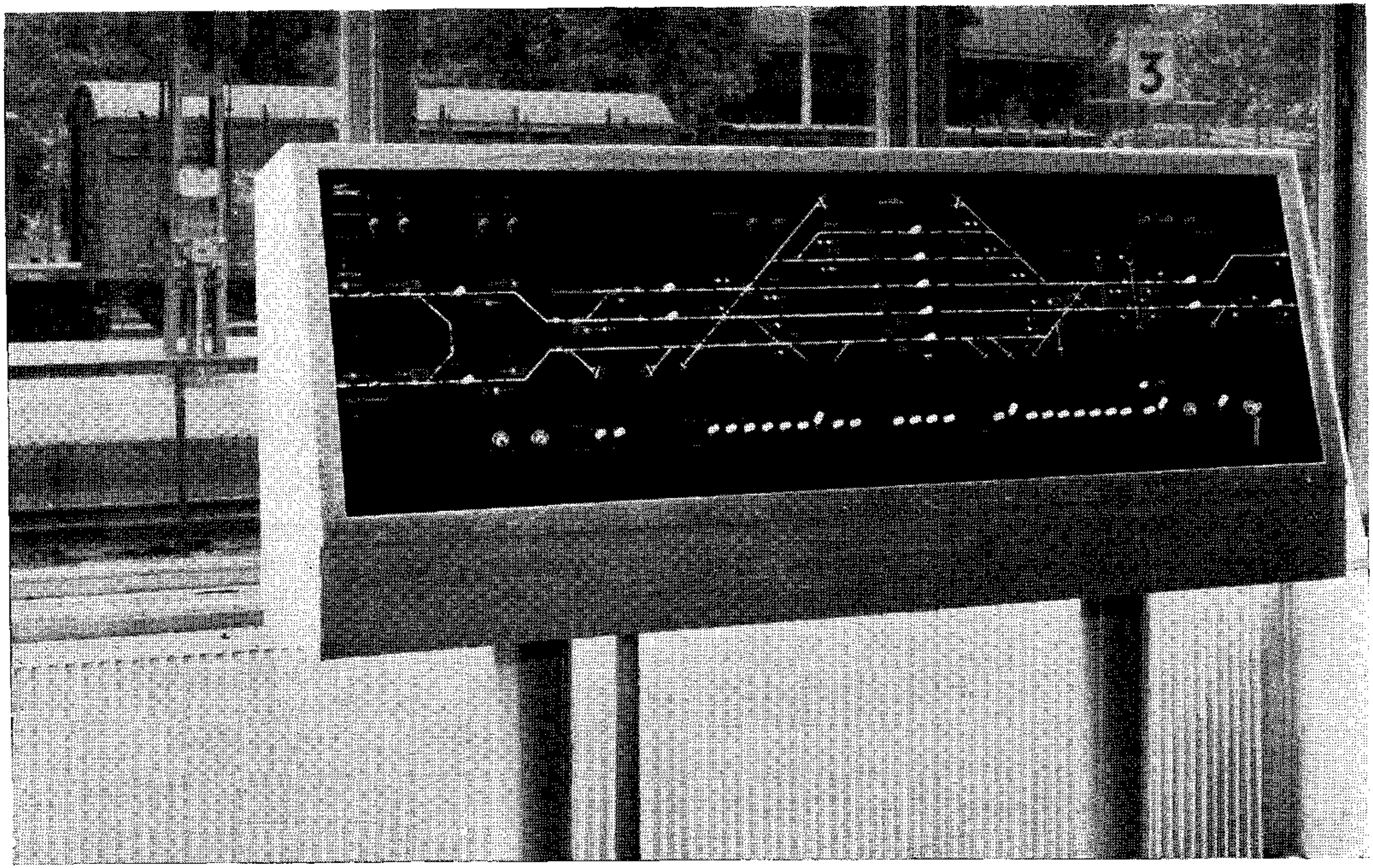


Fig. 2 The Control machine at Kolbäck

covers 758 km. of single track with 82 stations.

ALL-RELAY SIGNALBOX FOR SMALL STATIONS

The main aim in the design of this signalbox has been that it should be remotely controlled and that the interlocking functions should be entirely met by the local plant. There are therefore track circuits on all main lines, points are switched by electric point machines—pneumatic point machines are being used in Sweden only on trial at one marshalling yard—and complete signalling is employed with main signals in and out from all main lines. At double track stations there is complete signalling even to and from the right-hand track. The interlocking is, of course, carried out entirely on relays. A characteristic feature is the wide use of magnetic stick relays. With these relays the plants are not disturbed by brief interruptions in the circuits, a feature which has greatly simplified the power equipment.

The local control machines have non-locking levers (fig. 2). A route is established by operating two keys, placed in the track on the track diagram, whereupon the points assume their correct positions automatically. For switching of individual points there are keys at the bottom of the track diagram. At the C.T.C. stations the track diagram also has keys for operation of the contact line circuit-breakers. In preparation for C.T.C., certain storage facilities have been introduced for route controls.

An important factor in the design of the signalbox was the production of a suitable relay having a sufficient number of contacts and occupying little space. Earlier relays had been of the American kind which were very large and had few con-

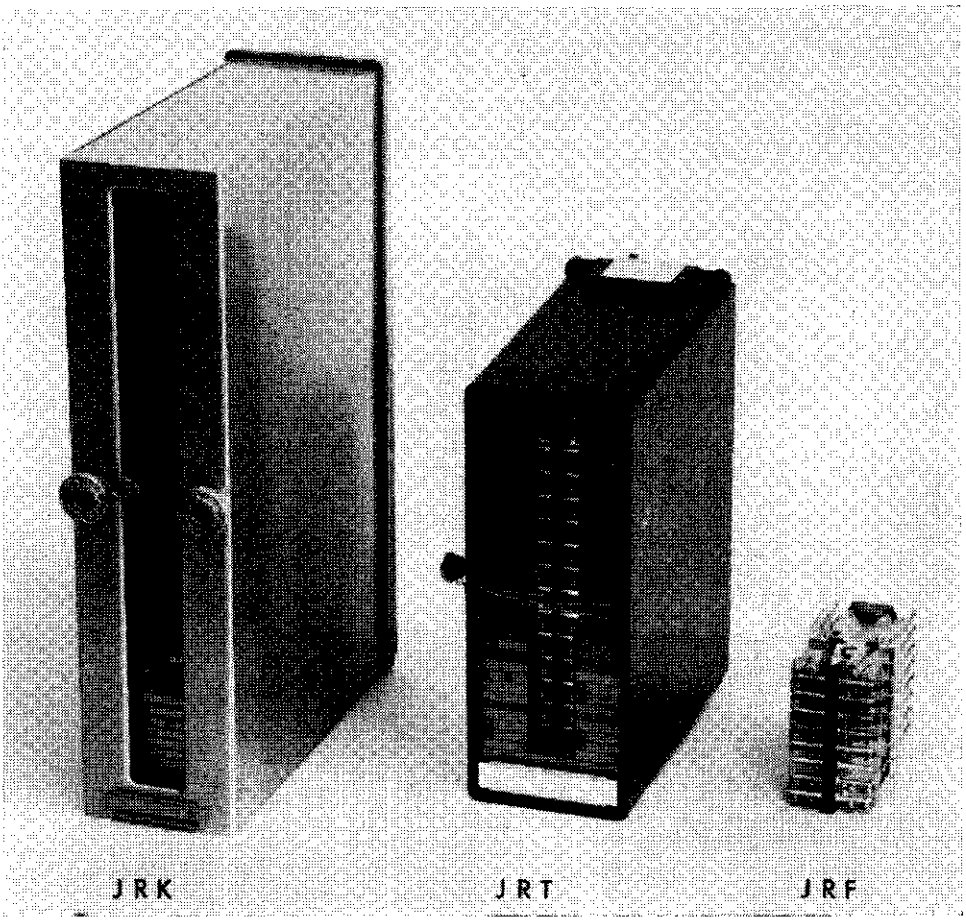


Fig. 3 Signal relays type JRK, JRT and JRF

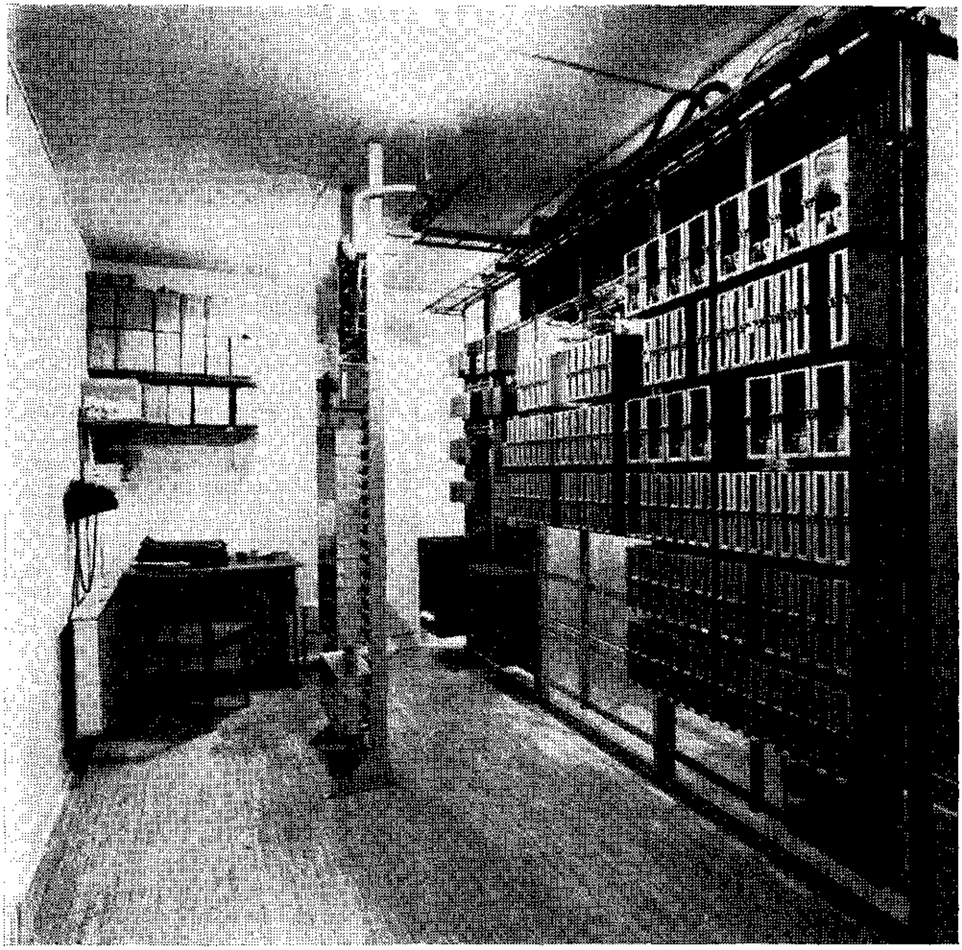


Fig. 4 Relay racks for a C.T.C. station

tacts. In collaboration with the L.M. Ericsson Company, which also had a hand in the development of the relay signalbox, the S.J. designed the JRK relay which, compared with earlier types, is a compact relay of plug-in type with silver contacts. Quite recently L. M. Ericsson have placed in production a new relay, the type JRT, in which the spring pressure on the contacts is accomplished by torsion. This relay is smaller and well suited to mass production. It needs no contact adjustment and is cheaper than the JRK relay. It will be used in all new plants. These two types of relay are among the three shown in fig. 3.

The first relay signalboxes were installed at Anderstorp and Stehag in 1950. Our present type, SJ 59, grew partly out of the experience gained from these initial installations and the design work may now be regarded as complete.

The relay racks for a C.T.C. station are shown in fig. 4. The larger rack on the right contains the equipment for the local signal box, with the power plant in the background; the signal relays are of type JRK. The rack on the left contains the C.T.C. equipment with control receivers, indication transmitters and function relay sets. The power equipment especially could be kept simple since we have a railway 50 c/s network (at 10,000 volts) laid on the contact line poles all along the line, so that the local supply is employed partly as a standby. Only at the very large signal boxes, or where there is no local supply, do we use diesel-electric units for standby purposes. We also have portable standby units which can be put in as needed.

Batteries are normally not employed, the signal relays as well as the remote control equipment being fed directly from rectifiers.

Interlocking for large stations

When it comes to relay interlockings for large stations, we must admit that our technique has not yet been stabilised. We have built a few interlockings—by British standards undoubtedly small—for which we have employed generally the same circuitry as for the electromechanical signalboxes. But the planning of such an interlocking takes a long time, as also does its installation, with the very extensive wiring involved. The testing of the finished installation is also a lengthy business.

Therefore, since several large interlockings were required, for Stockholm and elsewhere, we started a few years ago, in collaboration with L. M. Ericsson, to study a system of geographical circuitry. A trial installation at the Kiruna iron ore yard, incorporating 50 sets of points, has been in operation since the middle of 1960. It is made up of JRK relays—which are altogether too large for this purpose—but the object was to try out the switching technique. The JRK relays have, however, been combined into groups, for points and signals for instance, and are interconnected by plug and jack. The remaining work now lies chiefly on the equipment plane. The question here is what kinds of signal relays will be needed for different purposes. We have a long and successful experience of metal contacts in our signal relays and therefore we think it preferable to use one type of relay in the control part of an interlocking plant, that is, the part which controls point motors and signals, and another, smaller type within the logic equipment which checks the interlockings in the plant. A division of functions on these lines may also be of value inasmuch as it is one step on the way to forming the logic equipment out of components other than electromechanical relays.

A prototype for a signal relay of small dimensions, which is cheap enough for use in the large numbers required in such plants, has been produced by L. M. Ericsson and is the type JRF, the third of those shown in fig. 3. The new technique cannot, however, be employed in the Stockholm plant since the installation work has already started. This plant nevertheless possesses several interesting innovations, including an advanced control system, and will be described later.

AUTOMATIC BLOCK SYSTEM

The automatic block system of the Swedish Railways has been standardised inasmuch as the double tracks have been equipped as two single tracks, which means that we can drive at full speed and with block sectioning on the right-hand track as well as the left. After lengthy discussions concerning the risks of confusion between the signals for the two tracks, we decided to use identical main line signals placed on the outside of the tracks, as opposed to the earlier practice when dwarf signals were required for right-hand track movement. We have a three-aspect block system, modified insofar as the state of the second block section forwards is indicated by a separate distant signal if the length of the first section is more than 2,500 metres. Overlaps are employed only in exceptional cases out on the line, mainly when there is a stop immediately beyond a signal. In such cases we attempt to provide an overlap of 300 metres.

Hitherto the automatic block has been operated solely on the basis of continuous track circuiting. The condition for a block section being signalled free is that its track circuits are unoccupied and that, if a train has passed the forward signal, the signal shall have been passed when displaying the "proceed" aspect and thereafter switched to stop. We have at present no direct check of the passage of a train in the sense that, if a train has entered a block section, it must have passed out before the section can be released. We considered it sufficient to introduce a delay, requiring that the track circuits must be free for at least 5 seconds before the "proceed" aspect is displayed again. This has proved quite satisfactory so far since at present we have automatic blocks only on fairly heavily trafficked lines and furthermore are little troubled by rusting of rails, but if automatic blocks are introduced later on less busy lines it may be necessary to introduce a form of check of passage.

One assumption in the design of the automatic block system was that the telephone cable, which had been laid at the time of the electrification of the line, would be used for the transmission of the necessary signalling aspects. Since these cables were often laid many years ago, the number of wires is small, so that only one pair of wires per track can be used for line block purposes. In other respects the line block uses ordinary signal relays. Block posts and track circuits are fed from the aforementioned power circuit via a small transformer and since no local supply is usually available along the line, standby batteries are provided at these points. It is questionable whether this feature is necessary, as our own supply system is very reliable. It has its value, however, in allowing a greater freedom when work is needed on the contact line network. TGOJ, on the other hand, does not use standby batteries on its lines.

Investigations have very recently started concerning the possibility and suitability of arranging an automatic block using point checking instead of track circuits. The reasons are, firstly, that to a large extent we all-weld the track and as far as possible wish to avoid having to put in insulated rail joints; secondly, that the track circuits have a fairly high fault rate; and thirdly, that through an arrangement known as brake control, we do not need to use axle counters. The brake control, which for the Swedish Railways was developed by Mr. Karsberg (former-head of the Electrical Department), consists of a pneumatic cylinder inserted in the through pipe of the last coach. This device delivers pneumatic impulses to the through pipe at a few seconds frequency, the impulses being recorded by a receiver in the driver's cab. If any fault occurs in the through pipe this is immediately made known to the driver. As long as the impulses are being received, he knows that the whole train is intact, and the through pipe as well (no shut cocks). Trials are in progress with this arrangement and the results so far have been satisfactory.

TRACK CIRCUITS

SJ normally employs d.c. track circuits. Only one rail is insulated, the other serving as a return for the traction current, but only in part since a separate return circuit with booster transformers is arranged along the line. Both rails are equipped with rail bonds. Since only one rail is insulated, a d.c. track circuit may be affected by earth magnetic currents, which cause a voltage drop in the continuous rail. A thorough study has been made of these earth's magnetic currents. They are caused by solar eruptions and though of d.c. character alternate slowly in

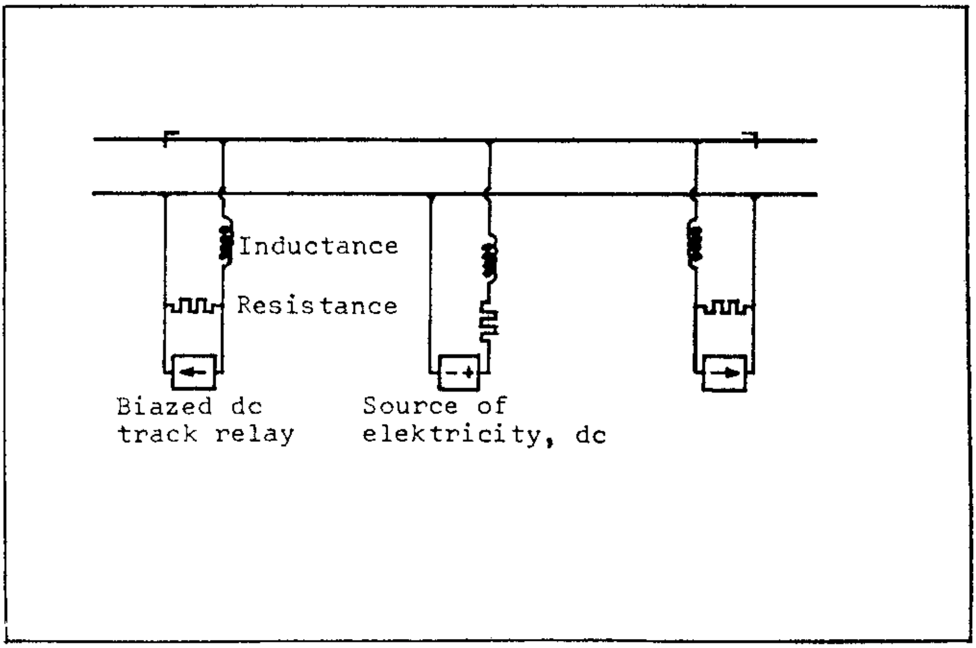


Fig. 5 Track circuit as used on electrified lines

magnitude and direction. The magnitude of the disturbing current is highly dependent on the resistance of the soil, so that, in southern Sweden for instance, with its chalky soil, no such disturbances occur. Test sections have been arranged for measurement of the disturbance voltage and voltages of 10 V. per kilometre have been recorded.

After extensive study and computation the normal track circuit equipment was established as shown in fig. 5. The track relays have a resistance of 30 ohms, the resistance in parallel is 15 ohms, and the reactors have a resistance of 3 ohms and a reactance of 400 ohms at 16 2/3 c/s. The operate voltage of the track relay is 1.4 volt and the release voltage 0.7 volt. The track circuit is fed with 6 volts d.c. from a rectifier which, when required, can be switched in parallel with a battery at places where there is no standby. The track circuit must be so adjusted that the track relay releases when the track voltage drops below 1 volt. With the prevailing ballast resistance, this means that a d.c. track circuit can have a length of about 1,500 metres. If the track circuit is longer than 300 metres, it has two track relays, as shown in the figure, both of which must be operated to indicate that the track circuit is free. The relays are polarised, and their polarities are arranged such that an earth-magnetic current can operate only one of the relays.

This d.c. track circuit is simple and fairly cheap, and is therefore used on the line and at small stations. At large stations, where it is an important advantage to be able to work with large distances between the end of the track circuit and the relay, two-phase a.c. track circuits, 75 or 100 cycles, are used. We are at present studying the new types of v.f. track circuits, with a view both to the possibility of superimposing track circuits for level crossing installations on existing track circuits for line blocks and to the eventual elimination of insulated joints in all-welded rails.

C.T.C.

General

The first C.T.C. installation in Sweden was commissioned in 1938 on the Stockholm-Saltsjöbaden line. The Swedish Railways' plans for the introduction of C.T.C. were interrupted by the Second World War, and it was not until 1955 that the first plant was installed, when the Ånge-Bräcke line was placed under C.T.C. operation.

This was a trial installation (developed in co-operation with L. M. Ericsson), extending for only 31 kilometres and having 4 intermediate stations. This single track line was so heavily loaded that a second track was considered necessary. But the introduction of C.T.C. and the construction of two sidings meant that the question of a second track could be left in abeyance. The experience afforded by this first installation surpassed all expectations and the installation of C.T.C. is continuing, on some lines to increase the traffic capacity, on others to save manpower. Today the Gällivare-Riksgränsen line (230 kilometres, 22 stations) is controlled from Kiruna, and the Ånge-Långsele-Mellansel line (253 kilometres, 27 stations) from Ånge and Vännäs. The Ljusdal-Ånge line (104 kilometres, 12 stations) will soon be in operation, and the Swedish Railways will then have the longest C.T.C. line in Europe, Ljusdal-Mellansel (357 kilometres, 39 stations). C.T.C. is also being built for the following sections of line: Lulea-Boden - Gällivare (204 kilometres, 20 stations), Mellansel - Vännäs (120 kilometres, 11 stations), Uppsala-Gävle-Ockelbo-Storvik (229 kilometres, 26 stations), Krylbo-Frövi (107 kilometres, 10 stations), Järna-Åby (108 kilometres, 8 stations) and Gothenburg-Halmstad-Ängelholm (217 kilometres, 31 stations). All these equipments were supplied by L. M. Ericsson.

TGOJ placed the first part of its C.T.C. plant in operation in 1958; the last part, 46 km. of the 309 km. line, is at present being installed. The equipment is being supplied by Siemens.

The Stockholm underground, which is operated by the Stockholm Tramways Company, has 99 km. of track under remote control from two control offices. But this is a direct-operated multiwire system. It also uses cab signalling. The supplier was the Swedish Wireless Telegraphy Company.

The Swedish State Railways C.T.C. system

The principle of the system is shown in fig. 6 and its characteristic features are as

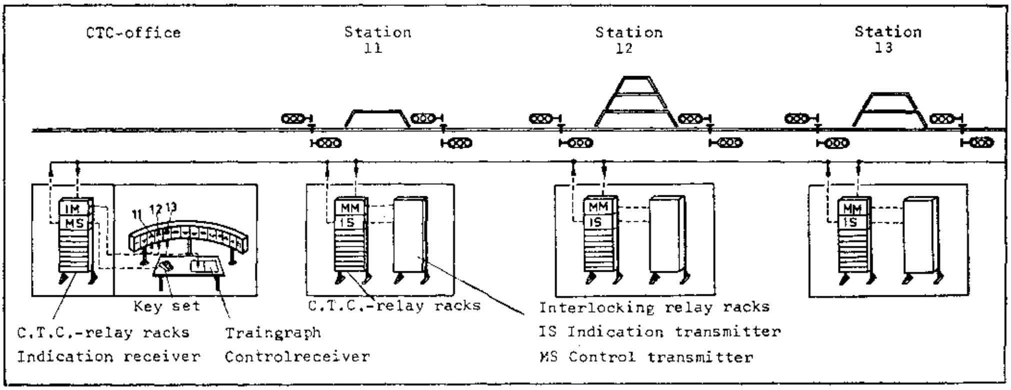


Fig. 6 The principle of the C.T.C. system

follows: Both controls and indications are sent on a two-wire line. The system is made up of a control section and an indicating section. The control equipment consists of a transmitter in the C.T.C. office and a receiver at each station. A maximum of 32 receivers can be connected to the transmitter. A transmitter can send 64 controls to each of the receivers.

The indicating equipment consists of a receiver in the C.T.C. office and a transmitter at every station. Thirty-two transmitters can be connected to the indication receiver, each of which can send 98 indications. The system can operate on any two-wire line having a resistance of up to 5,000 ohms and a capacitance of 8 mfd. If the line consists, for example, of

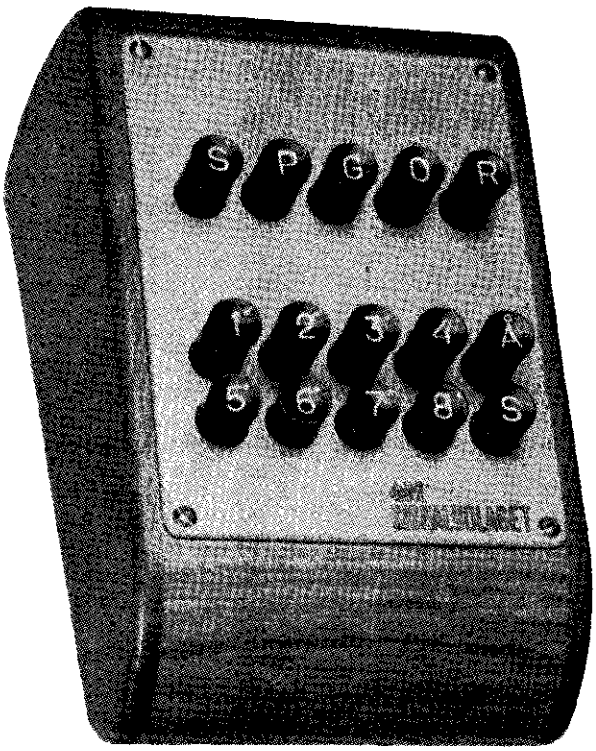


Fig. 7 Keyboard

a 1.3 mm. pair in a telephone cable, the distance from the C.T.C. office to the most remote station can be 200 kilometres.

Over longer distances between C.T.C. office and stations, controls and indications can be sent by carrier. If the line is occupied when a control or indication is to be sent, the control or indication is stored until the line becomes free.

The indication transmitters operate on a cyclic basis. This means that if several transmitters wish to send simultaneously, the last transmitter to send cannot send again until all waiting transmitters have had their turn. An indication transmitter can thus never be forgotten.

When a queue has formed, controls and indications are sent alternately. Controls are sent to stations from one or more keyboards (fig. 7). Controls and indications are sent on the line as a series of d.c. pulses of varying polarity—the control pulses at 220-280 V., depending on the length of the line, the indication pulses at 24 V.

A control is sent in 0.6 sec., an indication in 1.1 to 1.4 sec. Normally, however, several indications are sent simultaneously, so that the time for each indication is considerably shorter and the total time for 98 indications is about 7 sec.

The relays used in the system are normal telephone type relays. These are assembled groupwise on racks, each group relay set being a plug-in unit.

The C.T.C. system can be augmented by train identification equipment which provides identification on the track diagram of the categories of trains using the line, e.g. express, passenger, goods, etc. The C.T.C. operator also has a train graph recessed into his desk, .i.e an apparatus which records train movements in the form of a graphical timetable.

I will describe in somewhat greater detail how the system of controls and indications is built up.

Every station has a 2-digit number. Every control likewise has a 2-digit number. The latter numbers are arranged in a logical order which makes them easy to remember. Control 11, for instance, signifies the approach of a train from the north (train with odd number) to take the main route, control 13 the approach of a train from north to enter the longest siding. Similarly controls 12 and 14 signify approach from the south (train with even number) to main route and longest siding respectively. These control numbers are the same for all stations.

The digits keyed on the keyboard are converted into current pulses. Every digit corresponds to three pulses, positive or negative.

To select one of 32 stations, five current pulses are required ($2^5=32$).

For the control itself (the last two digits keyed) all six pulses are utilised, giving $2^6=64$ combinations for every station.

The 4-digit number that has been keyed is stored in relay registers. On depression of the start button 'S' a control transmitter scans the registers and sends the control out on to the line. The first five pulses (the station pulses) are received by all stations connected to the line, but the last six pulses (the control pulses) are received only by the station whose receiver is set to the station number concerned. The last pulse is of rather longer duration than the remainder. This is used as a check that transmitter and receiver are operating in synchronism.

In response to the series of control pulses the control receiver delivers a pulse to the station signalbox (voltage being applied to one of 64 wires). This pulse persists for 1 second, after which the receiver is disconnected.

The transmission of indications starts automatically as soon as a change occurs in any function at a station. The transmitter first sends the five pulses representing the station number. It then investigates the conditions of the function relays. As already mentioned, these may number 98 and are controlled by the local interlocking relays which mark the positions of points, signal aspects, occupation of track, etc. They are divided into 7 groups having 14 in each group. To reduce the time of indications, the transmitter scans only that group or groups in which a change has taken place.

If changes have occurred in all 14 groups, the indication will consist of $5+14+(7\times14)=117$ pulses.

The indications are displayed with great clarity on a track diagram of semi-circular form placed at such a distance from the operator that he has a good survey of the entire line. A C.T.C. panel of this kind is shown in fig. 8.

To keep the C.T.C. panel as simple as possible, only the most important indications are displayed on it, i.e. the

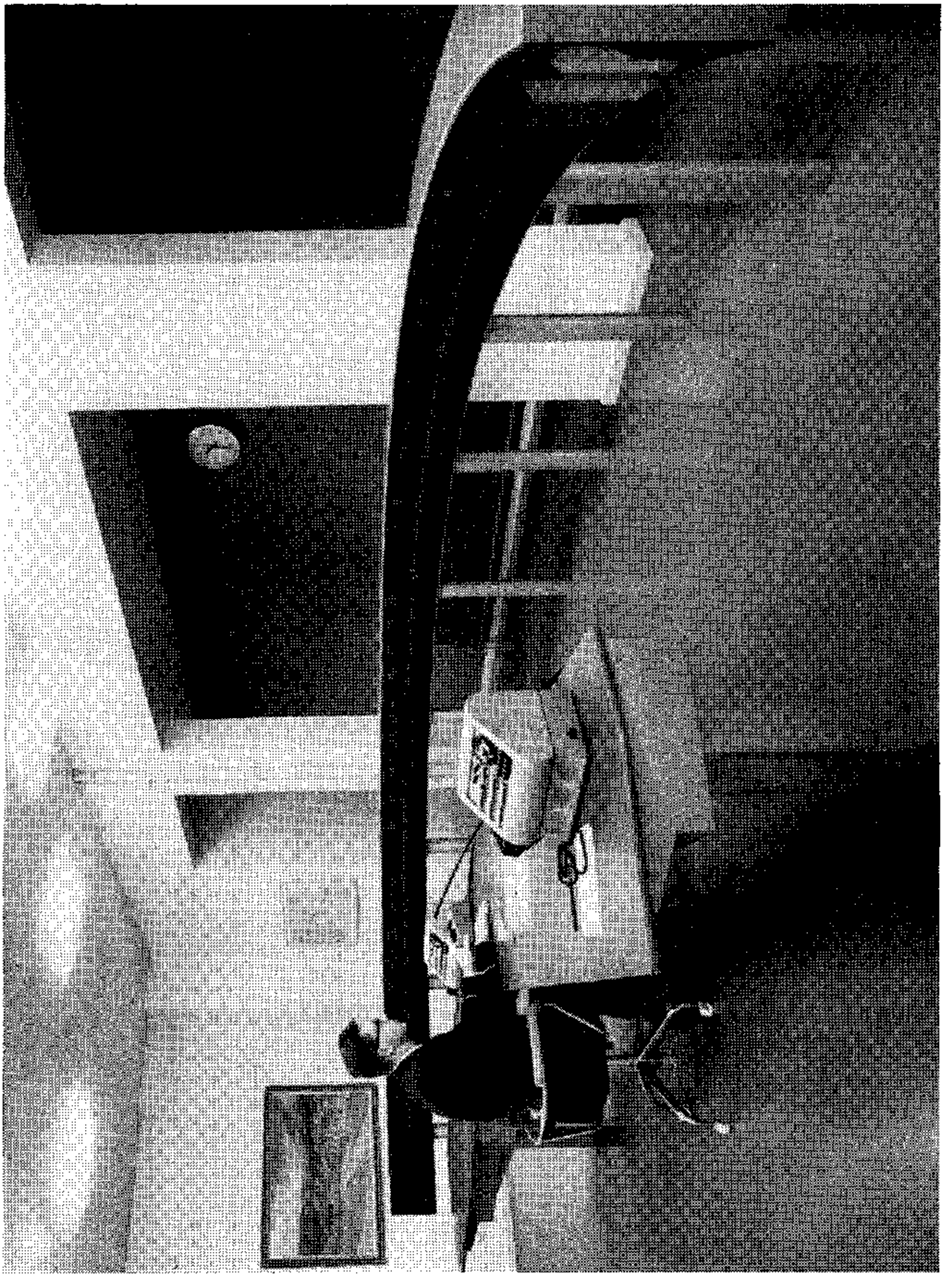


Fig. 8 The C.T.C. control at Ånge

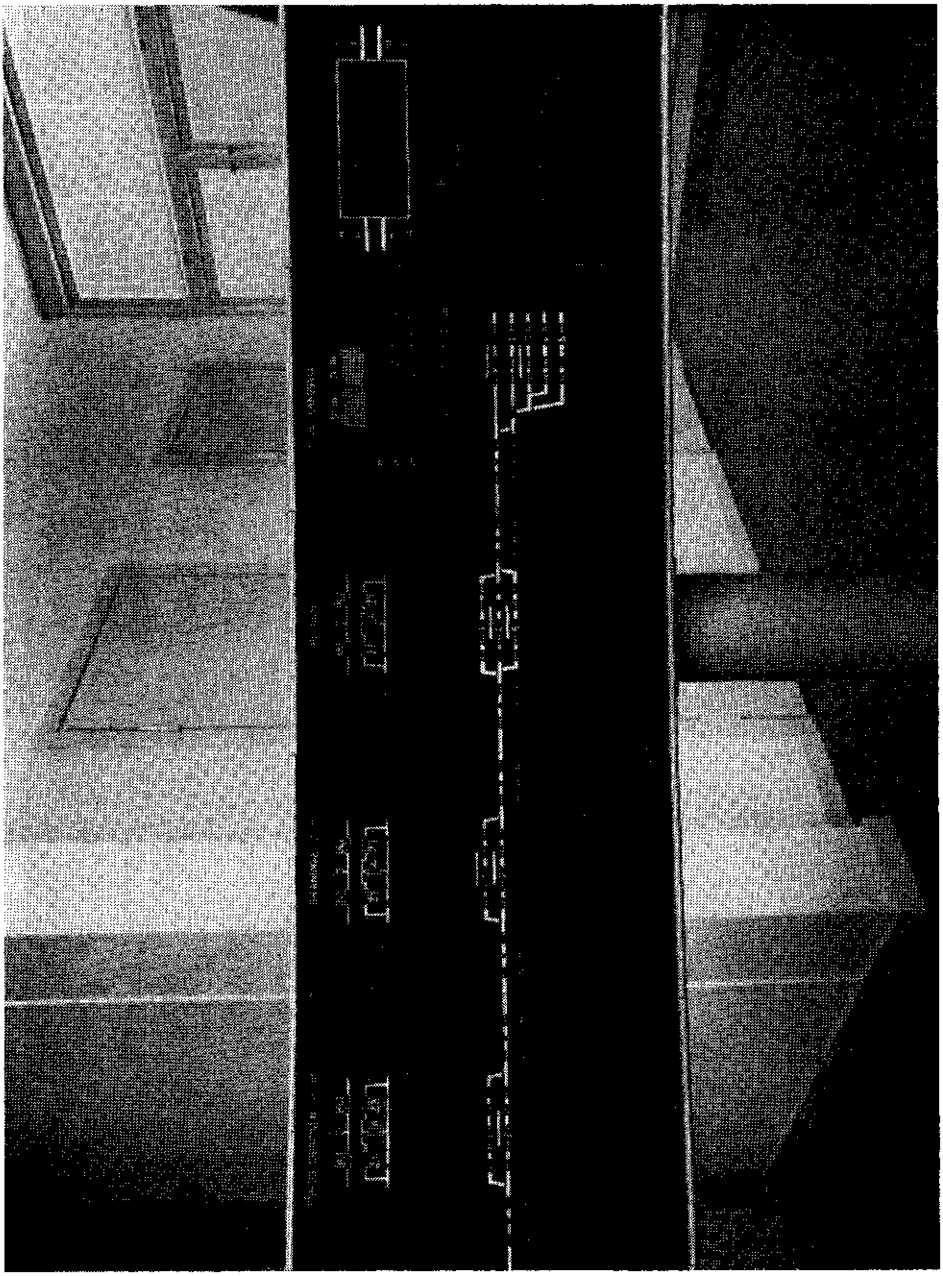


Fig. 9 Close-up of the C.T.C. diagram

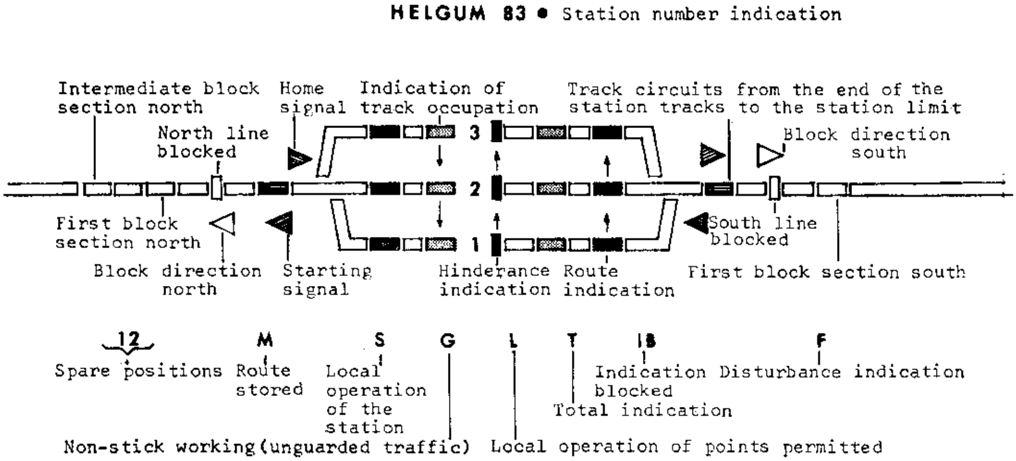


Fig. 10 Detail of the C.T.C. diagram with explanations of the symbols

positions of trains, the routes, and the more important signals.

When a complete check and display of all indications from a given station is required, i.e. of such matters as the position of every pair of points, or the connection of snow-melting devices, the station is connected by a special control to a total indication panel. This is placed within the C.T.C. panel and is common to several stations from which such indications are required.

Figs. 9 and 10 show a close-up and descriptive details of the C.T.C. panel.

It has been found expedient to introduce the possibility of storing route controls. This is done in a simple way in the local signal equipment. For a passing move at a station, for example, all controls can be transmitted at one time, after which the entire operation is arranged automatically. One may also arrange for the trains themselves to set up the necessary pulses for the route control.

The C.T.C. system has been proved to operate reliably and smoothly. No disadvantage has been found in the use of relays. In future, however, we intend to use static components (transistors) for transmitters and receivers, which should lead to a reduction of maintenance.

The separation of the control functions from the track diagram has proved a great success. Apart from the simplification of operation, the track diagram can be made up of very simple individual components, which is an advantage both for normal maintenance purposes and when modifications are required.

Contact line circuit-breakers and switches

Among their other functions, the station staff are responsible for the operation of the station circuit-breakers under the direction of the electrical controller. With C.T.C., as the station staff are to a large extent eliminated, these circuit-breakers must also be remote-controlled. This is usually done through a separate remote control system. SJ, however, employs a single system for both remote-control of interlockings and circuit-breakers. Hitherto the circuit-breakers and switches have been represented on the C.T.C. track diagram, but in future plants they will be operated by the electrical controller. TGOJ has gone a step further and placed the C.T.C. operator and electrical controller in the same building. The latter has a diagram of the contact line network with all circuit-breakers, and buttons on the panel for their remote control. He has in addition the same indications of train positions and categories as the C.T.C. operator. The contact line current transformers are placed at the stations so that when a fault occurs the electrical controller can ascertain on which section of the railway line it is located. He has a very good picture of the situation and can take quick action to limit the effects of a fault. This indication of the location of faults is of value to the preventive maintenance men and also enables them to decide whether the short-circuit is in a locomotive or on the contact line.

Fig. 11 shows the TGOJ electrical control room with its illuminated diagram

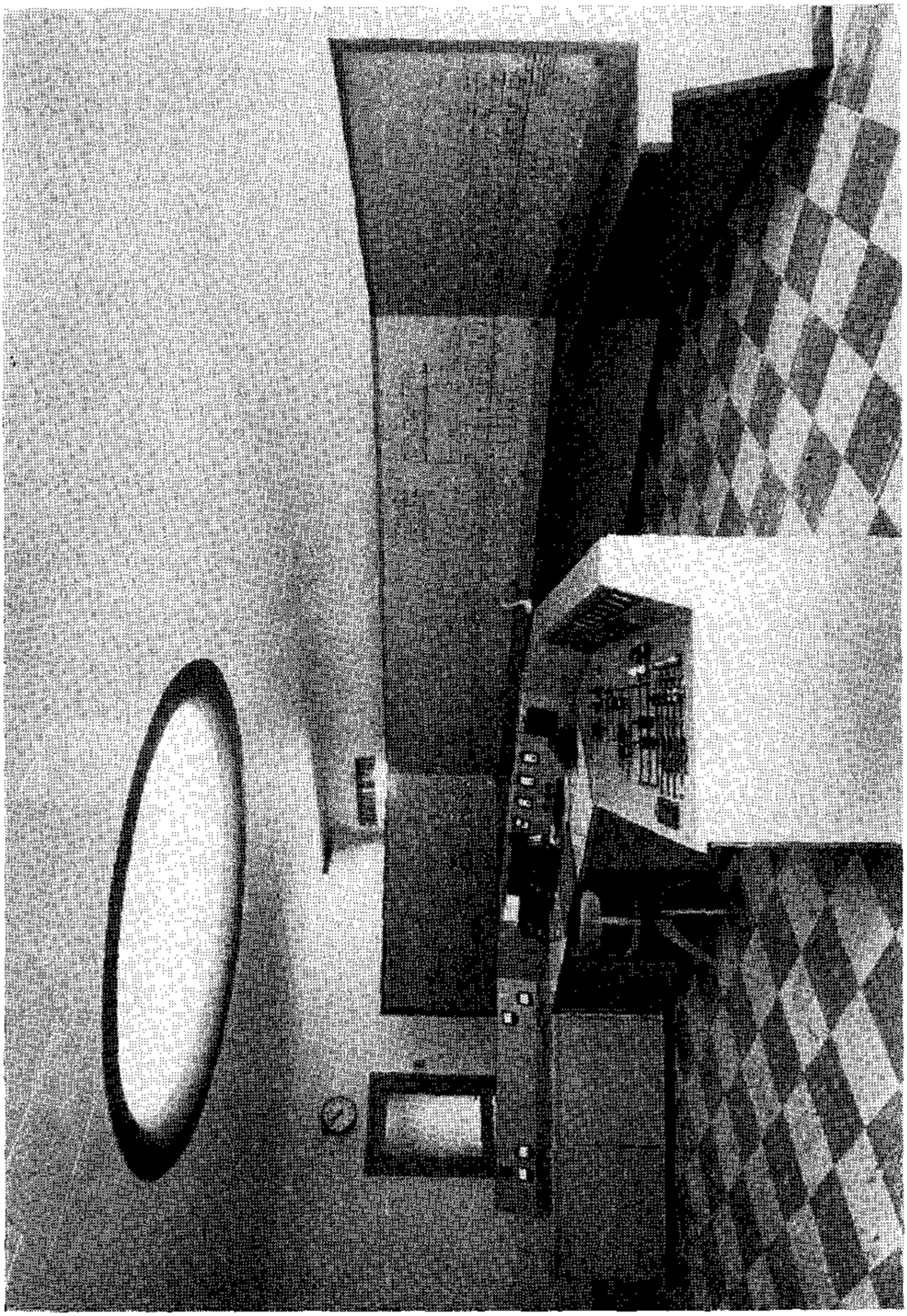


Fig. 11 TGOJ Electrical Control Room with control panel for circuit-breakers

of circuit-breakers and switches and, in the foreground, the control desk for the motor generator sets.

Planning of a C.T.C. line

The construction of a C.T.C. system must be preceded by meticulous planning. This is often a lengthy process since various departments are involved, not to mention the general policy of the administration. The first thing to decide is the volume of traffic for which the line shall be planned and what stations may be discarded or possibly may have to be added. Then one has to decide on the number of main tracks at stations, what changes may be needed in the free length of meeting track and what reconstruction of the track system may be required consequent on the reconstruction of platforms and through-tracks, etc. There is usually an accumulated need for alterations which must be examined and decided upon. Other questions are the location of the relay room, the need for added protection between main tracks and the part of the yard that is not controlled by signals, the future use of existing buildings, passenger barriers and the like. When one has reached this point, it is time for the signalling technicians to plan the plant. It may perhaps be pointed out that the C.T.C. system possesses a certain flexibility, which allows uncertainties to be left in abeyance to some extent. At all events the requirement should be imposed that plants not directly required by the C.T.C. system must in themselves be profitable.

Profitability of C.T.C.

It is impossible to calculate the profitability of C.T.C. in general, since there are many factors to be taken into account which may be differently evaluated in different cases and under different conditions. The estimate below related to the Ånge-Långsele plant.

The Ånge-Långsele line is 169 km. long with 164 km. single track and 5 km. double track. There are 18 controlled stations, 17 of which are on single track with one at the junction between the single and double tracks. The total number of trains per day in the two directions together is 64 on the Ånge-Bräcke and 44 on the Bräcke-Långsele section.

In conjunction with the installation of C.T.C. three new overtaking points have been constructed and the main tracks at some stations have been lengthened. The cost of these measures, amounting to 8·7 million kronor, is not included in the estimate since the investment is recovered through the raising of the line capacity. The installation costs are shown in the table below, which also lists the service capital costs.

The costs in this table are allocated among measures which raise the line capacity, measures which raise the safety level, and measures chargeable entirely to the C.T.C. installation. Opinions may differ about this method of allocation, and

Installation costs and service capital costs

Item	Investments, 1000s of kronor					Service capital costs for C.T.C.	
	Total	Raising of line capacity	Raising of safety level	Level crossing signals	C.T.C.	%	1000 kr
Ånge–Långsele line							
Interlocking plants	3,430	830	1,950		650	7.46	48,5
Automatic block sections	740	95	645				
Level crossing signals	185			185			
Remote control of circuit-breakers	235	15			220	7.82	17,2
Standby power equipment	105	15			90	7.82	7,0
Remote control equipment for C.T.C.	420				420	7.46	31,3
Point-heating	125				125	8.72	10,9
Telephone facilities	530	80	105		345	7.46	25,7
C.T.C. office accommodation	100				100	6.34	6,3
Misc. station equipment	90				90	7.82	7,0
Total:	5,960	1,035	2,700	185	2,040		153,9

the various headings may therefore require an explanation.

The interlocking plants are spread over the three headings of increased line capacity, improved safety level, and C.T.C. This line was equipped with old mechanical signalboxes which had long since been written off, and in any case did not offer satisfactory standards of safety in relation to the traffic density. For instance track circuits, exit signals, and automatic clearing of points were to a large extent lacking whether or not C.T.C. had been introduced, therefore new interlockings would have had to be installed. A small portion of the cost has nevertheless been charged to C.T.C. as the existing plants could otherwise have served a little longer.

The automatic blocks increase the capacity of the line as well as the safety, and are considered necessary on safety grounds. Mistakes may easily be made in the train announcement procedure and may lead to serious railway accidents involving very large sums.

Automatic level crossing installations are generally a very profitable investment owing to the saving of manpower for manual operation of barriers.

Remote control of the contact line circuit-breakers has been charged almost entirely to C.T.C., although at the same time it raises the standard of the traction system very appreciably.

Devices for thawing of snow at points are necessary for C.T.C. and are therefore charged to this account: with what justification is open to question, since point-heaters are generally warranted on lines carrying heavy traffic. The charge represents at all events a safety margin in the calculation. The remaining items call for no special comment.

This breakdown of the installation costs is inevitably a rather rough approximation. The standard of the service is raised in several respects—remote control of circuit-breakers, point-heating, better operation in general—and is difficult to evaluate in monetary terms.

The C.T.C. operating costs are set out below as additions or reductions in relation to the annual costs prior to the introduction of C.T.C.

The C.T.C. investment thus yields an annual profit of 478,000 kronor, i.e. an "extra yield" of

$$\frac{478 \times 100}{2040} = 23\%$$

Once again I must point out that this estimate does not take into account the raising of the line capacity and other indirect advantages brought by C.T.C. It should be recognised, therefore, that the profitability must be far better than the estimate suggests.

Cost Category	Ånge-Langsele	
	Addition 1000 kr/ annum	Reduction 1000 kr/ annum
Staff costs incl. reserve and welfare benefits		
Staff at existing stations, 30 men		554
Staff at new sidings, 10 men		185
C.T.C. operators, Ånge, 2.5 men	62	
Telephone maintenance staff, 0.5 men	12	
Signal maintenance staff for C.T.C., 2 men	42	
Inconvenience bonus and allowances for staff at existing stations and at new sidings		44
Postal revenue	12	
Power for point-heating	21	
Maintenance materials	2	
	151	783
Service capital costs as above	154	
	305	783
Nett sum of reduced costs		478

C.T.C. an integrating factor

Economic studies of C.T.C. systems in course of installation, the continuous rise of wages, the rapid technical development and the excellent results obtained from operating plant suggest that this form of automation can be carried to considerable lengths.

Consequently it is essential to draw up detailed plans for the future expansion of C.T.C. in order to avoid mistakes. There should be an overall plan for the entire railway network of the future, by which, in SJ, we mean the network which we expect to have left in 20 years' time. One may ask "Is it really realistic to count on C.T.C. on the less heavily trafficked sections of line?" In considering this question one must remember that C.T.C. can be arranged in different ways and that it would be unwise not to expect the future to bring technically simpler solutions which could permit C.T.C. to be used also on such lines.

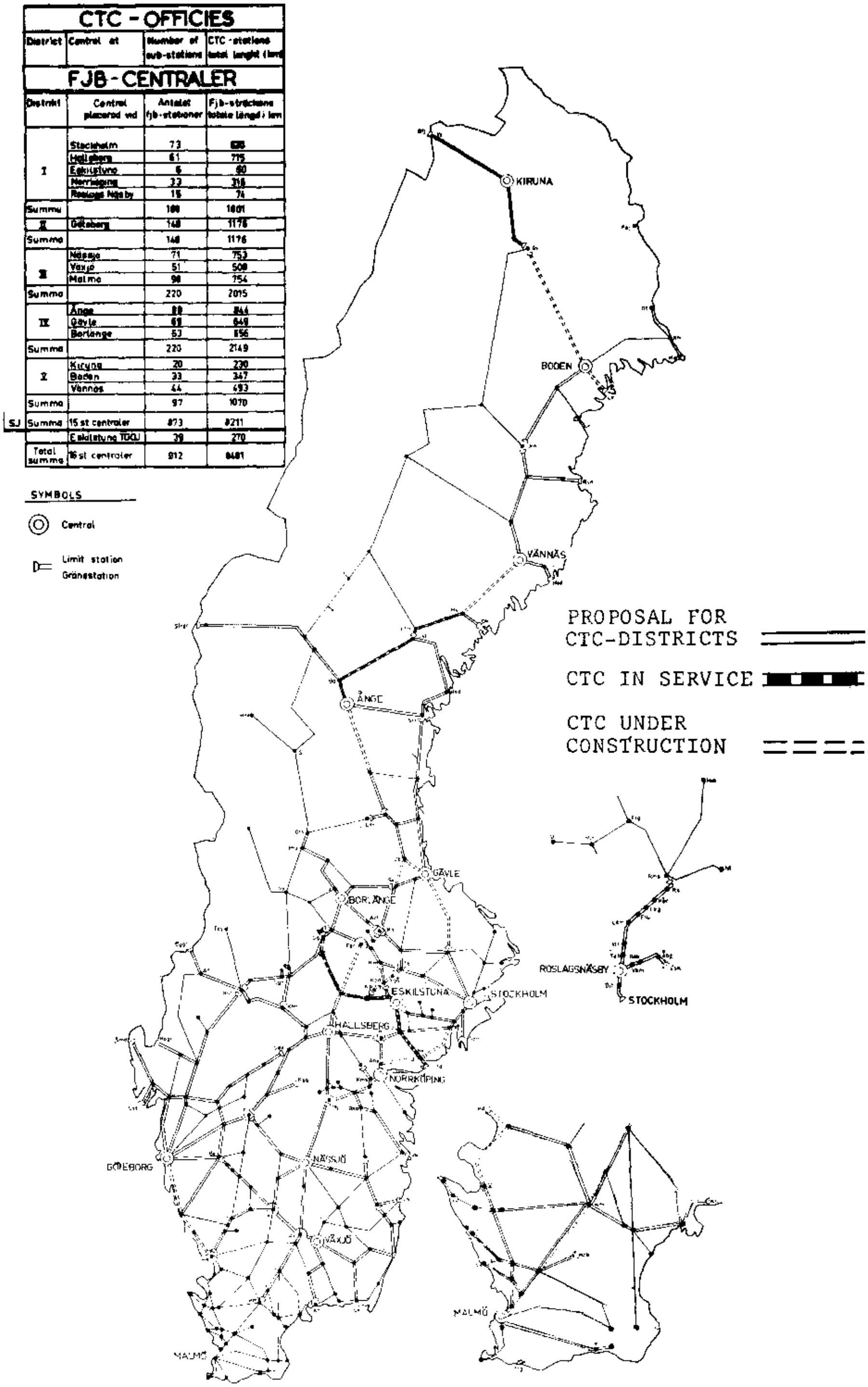
For such comprehensive planning certain questions immediately arise: *How large should the C.T.C. areas be, where should their boundaries lie, and where should the C.T.C. offices be located*?

There are various factors to be taken into account. As a general rule it is an advantage to be able to control over a very large area; one is then always well informed and can take the necessary action in time. Large areas also permit a greater degree of automation, human action being required only when disturbances and irregularities occur. An example is the train destination identification system in which a train is given a code number which enables it to establish its own route up to its final destination. This is a higher degree of automation than the storing of opposing train movements, as at present used by SJ, and frees the C.T.C. operator to a greater extent. Automation can be carried to different lengths, with greater or less simplification of the C.T.C. operators' work, in proportion to the capital available. Thus the size of areas will not be limited by the capacity of the individual operator. The staff of a large C.T.C. office can be increased or reduced according to the traffic intensity. This is of importance especially during the construction period. Experience hitherto shows that C.T.C. can be extended over very large areas. An important limitation, however, is the availability of wires in existing telephone cables. For this reason SJ normally counts on a maximum distance of 150-200 km. from the C.T.C. office to the most remote station. This makes a very large area, however, and it is questionable whether one needs to go further.

A C.T.C. office will become a very important central point within the area, and a large quantity of information will need to be passed to and from it. Telephone communication is therefore an important factor. The line telephone network must terminate in the C.T.C. offices, which must therefore be located so as to link up with the switching centres. Having regard both to the telephone cables and to the desirability of centralised control of a large area, the C.T.C. offices must also be conveniently located in relation to the railway junctions. The traffic structure is another important factor, and some guidance in its assessment is obtainable from the locations of the present traffic control points. The large streams of traffic, furthermore, should be controlled from as few points as possible. This is of importance, too, in determining the boundaries of the C.T.C. areas. Consideration must also be paid to junctions for L.C.L. freight, marshalling yards, locomotive depots, converter stations, the structure of the contact line network and, in fact, to all functions associated with the movement of trains.

The influence of goods traffic control will probably be of less importance, since its solution will probably come about through other measures.

A C.T.C. office should be the central point for all services concerned in the movement of trains, what one might call the train operations service. The C.T.C. operator must hold this entire process in his hand: he controls train movements, grants permission for work on the line, takes action when a fault occurs, etc. Within a large area, therefore, all work affecting train operations must be planned on a long term basis, be executed by large gangs, be co-ordinated between departments—all of which is already being done but, in future perhaps, may become still more important. It is likewise of importance for the C.T.C. operator's work that he has as few authorities as possible with whom to co-ordinate in respect of train operations within this area. Experience



CTC - OFFICIES

District	Central at	Number of sub-stations	CTC-stations total lenght (km)

FJB - CENTRALER

District	Central placerad vid	Antalet fjb-stationer	Fjb-sträckans totala längd i km
I	Stockholm	73	[illegible]
	Hallsberg	61	775
	Eskilstuna	6	60
	Norrköping	37	318
	Roslags Näsby	15	74
Summa		[illegible]	1801
II	Göteborg	148	1176
Summa		148	1176
III	Nässjö	71	753
	Växjö	51	508
	Malmö	98	754
Summa		220	2015
IV	Ånge	[illegible]	[illegible]
	Gävle	61	849
	Borlänge	63	856
Summa		220	2149
V	Kiruna	20	230
	Boden	33	347
	Vännäs	44	493
Summa		97	1070
SJ Summa	15 st centraler	873	8211
	Eskilstuna TDCU	39	270
Total summa	16 st centraler	912	8481

Fig. 12 Proposed subdivision of the SJ network into C.T.C. areas

has shown that telephone calls impose a greater load on the C.T.C. office than the work of switching signals for the trains. Within each large area, accordingly, there should be a co-ordinating authority for the permanent way, mechanical, electrical, signalling and telephone services. This gives an idea of how the C.T.C. areas will affect the organisational structure, and C.T.C. must be regarded as an integrating factor in the rationalisation of railway operation as a whole.

A proposed subdivision of the SJ network into C.T.C. areas is shown in fig. 12.

Traffic Centres

The principles outlined for the location of C.T.C. offices usually mean that they must be placed at large stations and combined with the local interlockings into what might be called traffic centres. This brings the following advantages:

a. Less need for exchange of information between the two staffs
b. The staff will have a good knowledge of the movements both in the outer and in the inner area
c. Teamwork between staffs for attainment of best results
d. In the event of trouble the entire situation can be quickly surveyed and action can be taken at remote points to relieve the pressure on the disturbed section of line
e. Equipment suited for automatic control on a major or minor scale, permitting minimal staff requirements.

A traffic centre of this kind is at present being built in Stockholm, comprising the local interlocking plant for the Greater Stockholm Area with the C.T.C. office located in the same room. The control room is shown in fig. 13. The interlocking control panel is seen on the left and the C.T.C. panel on the right.

The local interlocking plant extends from Älvsjö in the south to Sundbyberg in the west and Ulriksdal in the north—a distance of about 15 km.—and comprises goods terminals, locomotive depots, vehicle servicing shops, marshalling yard and harbour yards (fig. 14). In addition to normal train movements of 850-900 trains a day, a large number of shunting movements takes place within the area. The power signalbox will control 235 sets of points, 115 main colourlight and 307 dwarf signals, and will replace five previous signalboxes. Two of these, at Sundbyberg and Älvsjö, will be remote-controlled.

Various methods of operation of the interlocking plant have been discussed: keys on the track diagram, a desk with keys for each operation, or a keyset. We decided on the latter method because

1. we have very good experience of this system at our C.T.C. offices
2. it gives the operator a good overall survey of the situation and free desk space for records and the like
3. the system is rapid and allows division of the track diagram between a number of operators according to the traffic intensity.

The interlocking control board consists of an indication panel and one or more keyboards for route establishment and another keyboard for the keying of train descriptions.

In principle the only indications shown on the track diagram are those required by the operating staff at any moment. Normally, therefore, the positions of points and conditions of signals are not shown unless they form part of an established route.

An established route is indicated by a white line-of-light along the entire track for that route. The points on the route are indicated by a flashing white light while being operated. Once they have been operated, they are displayed as a steady white light. The entire route will thus be displayed as an illuminated white line. The routes on the diagram consist of main routes and shunting routes. The signals for the respective routes are marked by an arrow-shaped illuminated aperture for the main routes and by a sector-shaped illuminated aperture for the shunting routes. The signals are normally extinguished, but show the green aspect when the route is established. When a train enters the route, the signal changes to red and the white line-of-light changes successively to red as the train proceeds along the route. Signal and track indications are extinguished when the route is released. The routes are generally released sectionally. The illuminated line-of-light is thus extinguished behind the train. A stationary train, for example at a platform, is marked by a red light in the track.

The indication panel also has rectangular display units above each track section for displaying the numerical descriptions of

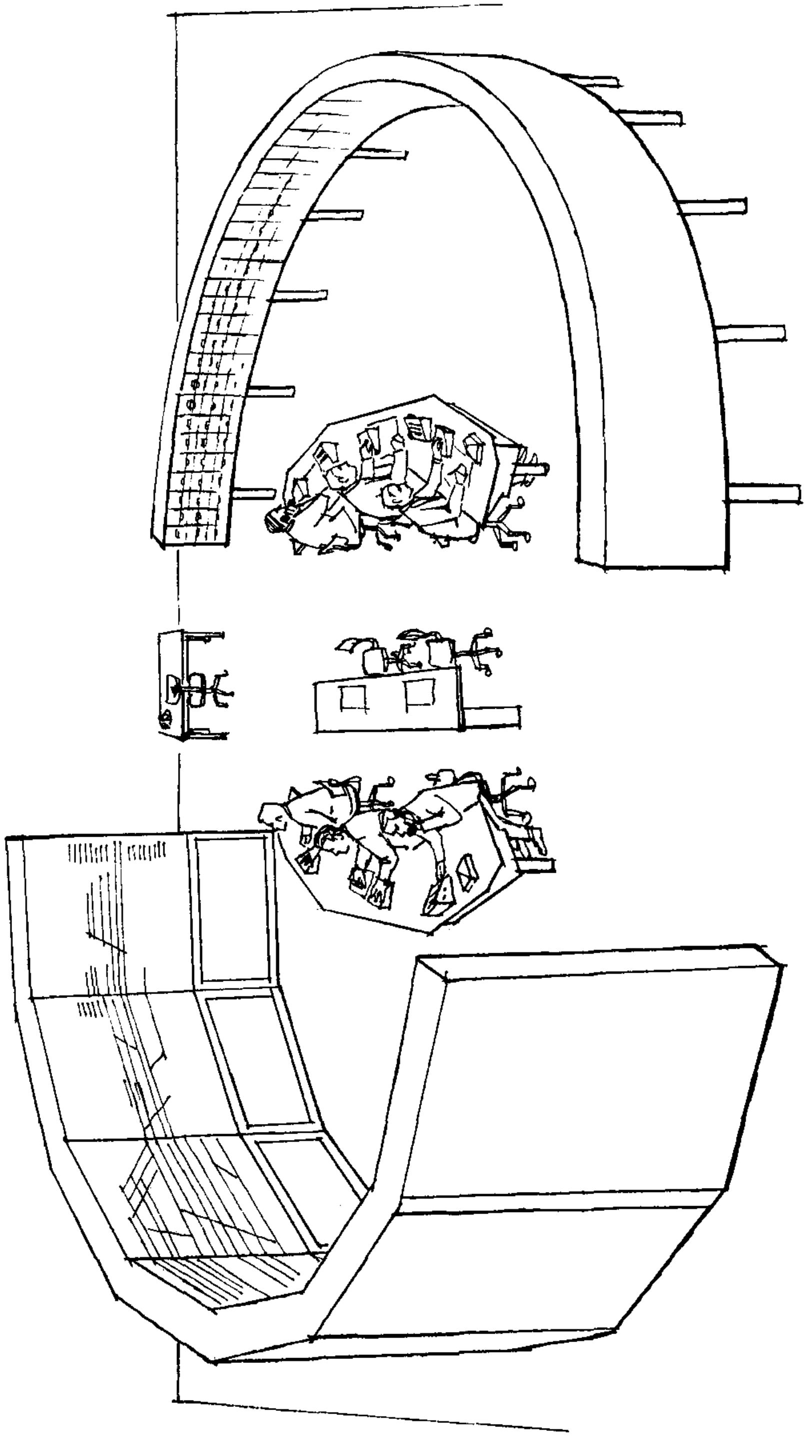


Fig. 13 Stockholm traffic centre

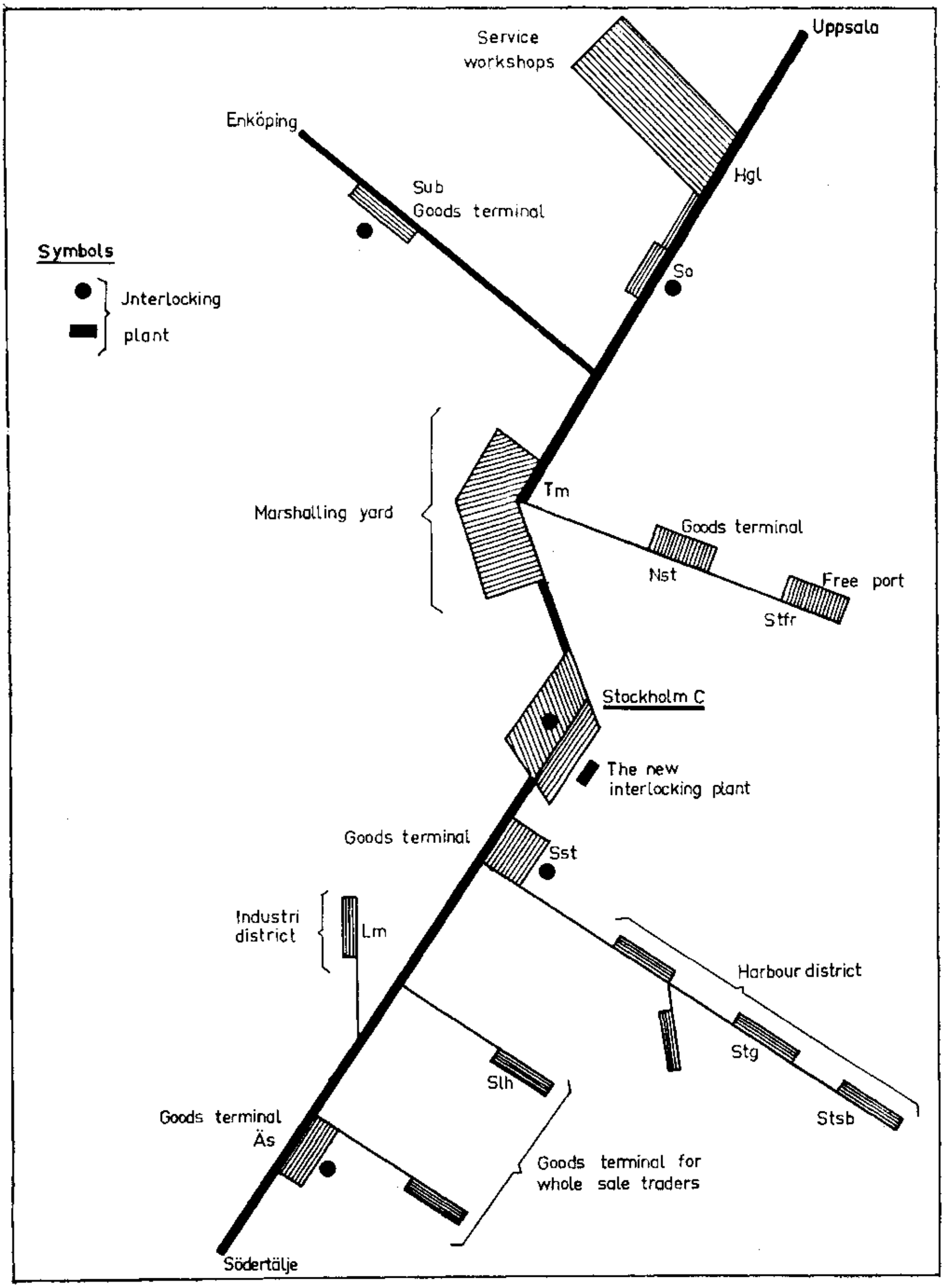


Fig. 14 Stockholm interlocking plant area

the trains in each section. The numbers are illuminated by small projectors behind the display units.

The establishment of routes, etc., is done from a keyboard. The keyboard has ten numerical keys marked 0-9 and a number of alphabetical keys. The numerals indicate the object to be controlled and the letters the type of control. Each signal and pair of points is marked on the track diagram by a three-digit number, the numbers running in numerical sequence. A route is established by keying the three-digit number of the signal at the start of the route and the number of the signal at the end of the route. The signals at each end of the route flash with a red light. After checking that the correct route has been established, the operator presses the alphabetical key for the main or shunting route. The points on the route are then automatically switched to their proper positions and the route is locked. To switch an individual set of points, the operator keys the number of the points and then presses the "Normal" or "Reverse" key.

Emergency release of a route can be effected by keying the signal number and pressing the alphabetical release key.

The control mechanism consists of miniature relays and crossbar switches. Routes can be stored, and steps have been taken to allow the later addition of equipment for automatic route establishment.

The question of train describer equipment for the Stockholm plant has been discussed. Such equipment is to be installed, and this will provide experience for future plants. An important point to be decided on is the use of train describer equipment for the large C.T.C. offices.

At Hallsberg a similar traffic centre is to be installed, combining C.T.C., local interlocking for passenger and good yards, and the marshalling yard control office and automatic equipment. From the same building a number of converter stations for the contact line network will be remotely controlled. It will also be the central point for remote control of the contact line circuit-breakers within the C.T.C. area.

LEVEL CROSSINGS

Ten years ago our level crossing installations consisted principally of automatic audible and visual signals on open stretches of the line and of manual barriers at stations. With the increase of road traffic we have acquired new audible and visual signalling installations, and also automatic half-barrier installations on open lines. At the same time our small stations have either been converted to remote control or have been equipped so that they can be left unattended during the greater part of the day. In conjunction therewith the level crossing installations at stations have also been made automatic, also barriers have been partly replaced by audible and visual signals, though not to the extent we should have liked. In 1961 we had 471 automatic level crossing installations with full barriers, 116 with half-barriers (fig. 15), and 1,874 with visual and audible signals alone.

The change from one type of safety arrangement to another, or the installation of safety equipment at a level crossing which previously lacked such equipment, may not be undertaken without the approval of the Board of Roads and Waterways. After this approval has been granted, the work is planned and put into effect by the State Railways. For all installation and alteration of safety arrangements which provide a higher protection for road users and involve no saving of cost for the Railways, up to 90 per cent of the cost of the installation is paid out of automobile taxes. These grants come from the Board of Roads and Waterways. For this reason, and to allow control of the growth and protection of highway traffic, the Board of Roads and Waterways participates in decisions affecting the safety of level crossings. In order that this co-ordination may proceed smoothly for the past eight years there has been a committee consisting of three members, of whom one, the chairman, is from the Board of Roads and Waterways, the other two being from the Board of Railways.

Our automatic installations are controlled by steady current track circuits—in the simplest case one long track circuit on each side of the level crossing and a short track circuit over the roadway. The function of the long track circuits is to assure a warning signal of sufficient duration (not less than 20 seconds) for approaching trains; it also forms part of the interlocking when the warning signal is broken off after the train passes the road.

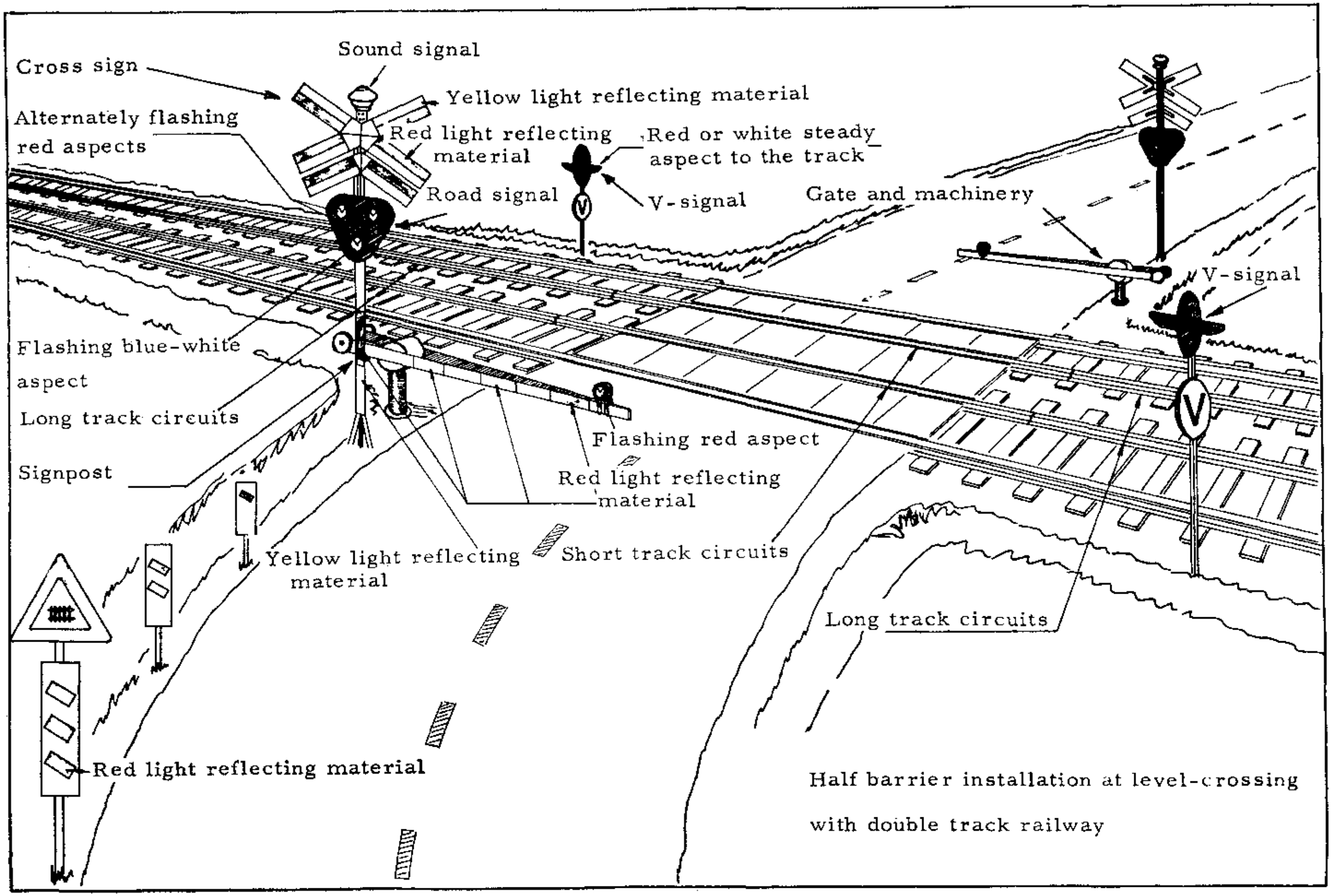


Fig. 15 Level crossing with half barriers

The short track circuit checks that, after the warning signal has started, it cannot be interrupted until the whole train has passed this track circuit or until all three track circuits have been unoccupied by vehicles for at least 2 minutes. The disconnecting function, which interrupts the warning signal when the whole train has passed the short track circuit, is controlled by means of a time relay or by main running signals. The plants are further equipped with a control signal to the track, situated at the level crossing, which gives a steady white or steady red light according to whether the warning signal for the road traffic has started or not.

CONCLUSION

Developments within the extensive field of signalling are advancing very rapidly. In a small country like Sweden we cannot conduct research over the entire field but must concentrate our efforts on a part of it. It is only in these last years, for instance, that we have begun to automatise marshalling yards, and the question of an automatic train stop has been left aside pending the results of the present U.I.C. investigation.

Design work within the C.T.C. field is being pushed ahead in order to obtain standards not only for the equipment but also for co-ordination with the remaining electrical system. The signal code can be improved upon and simplified, and much remains to be investigated as regards the rational utilisation of C.T.C. on a major scale.

The electrification of lines, which is now almost complete, has represented a great saving. It is our hope that C.T.C., as an integrating factor in our strivings towards railway automation, will be the next great modernisation measure within the electrotechnical field.

DISCUSSION

Mr. A. W. Woodbridge, opening the discussion said what a very fascinating experience it had been to hear Mr. Knall describe his own system in English. It was a considerable mental effort, and achievement, to attain a standard of delivery and fluency that was equal to that of many English people. His story was a very fascinating one, and he certainly need not have apologised for the small amount that the Swedes had done. He was quite convinced that by anyone's standards they had moved very rapidly in a complicated sphere. No doubt conditions must have been produced whereby they could do that. They had produced a result which was of very great interest to everybody. He thought they could congratulate Mr. Knall very specially in devising a C.T.C. equipment with a simple logical keyboard for operation. That seemed to him to be a great advance. Whether it would turn out as well in a big interlocking he was not sure, but he for one would be very interested to see how it eventually worked out.

Obviously Mr. Knall had not entered into great detail, but he had given them a general description of his plan for modernisation of signalling. It was interesting to see that their thoughts were now turning, perhaps, towards more automation and more novel ideas—perhaps static switching. Their developments will be watched with extreme interest, because their approach had been somewhat different from our own, and they could achieve what they wanted in a very quick time.

Mentioning two specific points; Mr. Woodbridge first said he was most curious to know how, in a small country of 7 million population, with 60,000 employees on 14,000 kilometres of railway, they managed to maintain all the equipment. Where did the men come from? How were they organised? He had better not ask what they paid them, but no doubt there was quite a big organisation, and if Mr. Knall could give some information about that, he for one would be very pleased.

One other feature that intrigued him was Mr. Knall's statement that the profitability of a C.T.C. scheme cannot be worked out. How did he justify it financially. In Great Britain they *had* to show profitability. Undoubtedly they in Sweden had considerable profit that they had not yet disclosed. Half a telephone maintainer gets 12,000 Kronor a year, which works out at something like £2,000 for one maintainer per annum. If, in Great Britain they had that standard of wages, no doubt they could justify a lot more expenditure than they did today. He thought that was part of the secret of their financial success.

Mr. Woodbridge concluded by saying how much they welcomed Mr. Knall's Paper, and how pleased they were to see his party in England.

Mr. J. F. H. Tyler said that one of the most interesting things about Mr. Knall's Paper was the theme with regard to the signalling which he was carrying out. There was a policy, and the policy was that power signalling was to be put in on the Swedish State Railways. He had found that approach in all continental countries; but for some reason which he could not understand it did not seem to apply here. It was necessary to justify each scheme individually, as Mr. Woodbridge had just said. In this country there was, as a minimum, semaphore signalling and telegraph block working, which had a higher standard of safety than was given by a dispatcher system; but nevertheless to go from that to fully automatic block did introduce additional safety, unfortunately they had to justify each individual scheme on its merits, that was by the economy resulting therefrom.

With regard to the technical details of the Paper, he was interested to hear the reference to overlaps, and he would like to know whether that was a new development on the Swedish State Railways. He was particularly interested to hear that overlaps were only provided at signals ahead of which trains stopped for service reasons.

He was also interested in the device by which impulses are passed through the train pipe to prove that the last vehicle on the train was present. If one had continuous brakes—he was assuming there were no track circuits—why was it necessary to have more proof that the train was intact.

Another interesting item was the 20-second minimum warning to the road user, as far as level crossing barriers were concerned. In Great Britain they had adopted the principle of keeping the warning as short as possible, so as to frighten the motorist, so that he did not attempt to cross the railway once the barriers had dropped. Was a maximum time specified, which must not be exceeded before the train arrived?

Referring in conclusion to page 109 he noticed that in Mr. Knall's calculation for the return on the C.T.C. investment the whole of the saving of 478 Swedish Kronor was related to the cost of the C.T.C. Should not the saving also be related to the increase in line capacity.

Mr. A. A. Cardani said that Mr. Knall had referred to the entire satisfaction given by a relay system of C.T.C., but in order perhaps to obtain reduced maintenance, static forms were being developed. He wondered if in addition to reduction of maintenance, the speed of operation was not also a factor entering into this development, especially in view of the long lines with this form of supervisory control. If so, he would be very interested to hear if Mr. Knall had worked out any formula, or relation, between speed of operation required for the system and the traffic density.

Mr. E. A. Rogers, thought that the discussion so far had shown everyone's growing concern in financial matters; and one of his leading questions was again on the question of cost and justification. He noted that about half the total cost of the complete installation was limited to improving or raising the safety level. Could Mr. Knall say whether his administration accepted a charge of that sort, and whether there was any standard basis by which a large installation could carry an increased safety charge without having to justify equivalent savings.

Mr. Knall's track circuit experiences seemed to conform largely with their own in dealing with the 50-cycle electrification, in that the D.C. track circuit had been found to be generally simple and economic. They had not yet used the two-relay solution. He would like to know what special steps were taken with D.C. relays to make them immune from operation of stray A.C. from the traction system, rather than through the earth magnetic leakage, and what were the limits which they set of stray A.C. voltage on these relays? Furthermore, on the same subject of track circuits, did he experience trouble in his D.C. feed sets through A.C.

leakage being rectified by the feed sets of the track circuit?

Mr. F. G. Hathaway said he would like to refer to Mr. Knall's remarks about automatic block. He said that at present the automatic block was solely used with continuous track circuit, but that they were looking at the possibility of automatic block using point checking instead of track circuits. He wondered whether Mr. Knall could give them some more information on exactly what they had in mind, and whether it tied up with his previous remarks that they had continuous track circuits as a means of proving that the entire train had gone through the block section; but for less busy lines in future it might be necessary to introduce a form of checking the passage of a train.

Mr. A. W. Woodbridge asked if he might put a supplementary question in connection with the level crossings. In the diagrams, no telephone was shown. Could Mr. Knall tell them how the car driver, who had pulled up against a barrier which had fallen, due to a failure, know when to proceed? In this country they were faced with providing a telephone which communicated to the nearest responsible railway authority, and that in itself could cost a lot more than a bridge!

Mr. G. W. Gore said he would like to ask a question about the track circuit shown in figure 5. Mr. Knall used biased relays to prevent the track relays from being affected by earth currents. Did that mean that both relays had to be energised when a track circuit was showing clear, and if so, did that not have serious reflections on cost due to the increased cabling complexity?

Mr. J. S. S. Davis said that the author made mention on page 113 that within C.T.C. areas there must be a co-ordinating authority for the Engineering Departments. Would Mr. Knall please say if this co-ordination was in respect of new works, renewals, or other works necessitating pre-arranged track possessions, and did it include a co-ordination of maintenance duties as well. In other words, were the station staff expected to deal with elementary maintenance matters such as fuse replacements, or replacing failed indication lamps. Equally, on the track were the permanent way maintenance staff expected to deal with the replacement of, say, signal lamps or renewing broken bond or rail connection for track circuits.

Mr. G. Knall, replying to the discussion, thanked Mr. Woodbridge, and the members present for their kind remarks and their reception of the Paper. He replied immediately to the various questions; the discussion as recorded in London and as printed in the preceding pages was submitted to him after he had returned to Sweden, and his full reply is as follows: "There were many questions about my calculations of the costs of C.T.C., and I would underline what I have said in my Paper, that it is very difficult to make such a calculation *in general*. There are many factors to be taken into account, which may be differently evaluated in different countries and under different conditions. For instance, in Sweden we are lucky so far that we have comparatively few complete mechanical interlockings and we are still running at 130 kilometres per hour without track circuit, exit signals or automatic clearance of points. These are not satisfactory standards of safety. An accident also costs a lot. So in this case I don't consider the raising of the safety level should be charged to the C.T.C. installation.

"The raising of the line capacity can either be charged to C.T.C. or pay for itself. In the case I mentioned in my Paper the traffic was very heavy and the alternative was to install double track on the line. A second track costs in Sweden at least 5 million Swedish crowns (average) per 10 kilometres. The whole section is 170 km. and it would cost 85 million SCr. as against 6 million for signalling and 8,7 million for track construction. In other cases the conditions may demand that we renew or replace fairly new interlockings, and then the profitability is not so good as I have calculated here. In the example in the Paper I have charged 650,000 crowns of the interlocking costs to C.T.C., as the existing plants could have served a little longer. In other cases it may be possible to reduce the number of tracks or cut out whole yards thanks to C.T.C.

"In Sweden we must justify each project financially as well. In the Paper I have shown a plan for the future expected expansion of C.T.C. on the entire railway network. It has not been decided to install the whole of it yet, but it is necessary to have such a plan for choosing the locations of the C.T.C. offices and so on. At present we have decided to install C.T.C. on about 1,000 kilometres of track and we are preparing another five years' scheme comprising 2,500 kilometres of track, and all of these lines are very profitable.

"Concerning overlaps the fact is, as I mentioned in my Paper, that we only use them on a small scale and we have no plans to extend their use.

"There was a question about the brake control device. It may seem as if this final check would be unnecessary, as there is a through brake. In point of fact we have had an accident in Sweden, which happened as follows. The emergency brake of a goods train came into operation and the driver sent his assistant along the train to find the fault. He found that the cock was open on the last wagon. He shut it, went back to the driver and told him what he had done, and they went ahead. However, he had not noticed that the train had lost some of the last wagons and a fast train came after and ran into them. They have recently had a similar accident in France, I believe. This is the reason why we must check the last coach even if we have a through pipe.

"Concerning the speed of operation of the C.T.C. equipment I can tell you that we haven't needed to use high speeds on our lines. The number of trains on our lines amount to 30–60 per day and we work with sections of about 100 kilometres; the distance between the stations is about 10 kilometres, which gives about 10 stations on every C.T.C. circuit. Only in one case, in the Stockholm area, has the speed problem arisen, and here we need three systems for remote control of two signalboxes. We have not made a general study of the problem.

"Mr. Woodbridge asked about telephones at level crossings and I generally say that level crossings are the most troublesome items we have within the signal field; they complicate the signal plants and there is a constant demand for modifications. We have about 2,500 automatic level crossings in operation and we estimate that another 2,500 will need to be protected in the future. Our construction capacity is 100 plants a year, and we think it more important to provide new crossings with protection than to invest the money in telephones and arrangements for limiting the maximum warning time. As a matter of fact the railways interfere very little with road traffic in comparison with the traffic blocks in the cities. We have not yet installed any telephones. The warning time of 20 seconds we have recently reduced from 30 seconds. It is difficult to say, whether we intend to go any further in the future.

"Concerning track circuits I can mention that we protect our D.C. relays and feed sets from stray A.C. from the traction system only by an inductance and a resistance, as shown in figure 5. The relay coil can stand 350 volts A.C. and we have no problem in this respect. The solution of making the track circuits immune from the earth magnetic leakage by using two biased relays is in our case not an expensive one, as we laid a telephone cable all along the line at the time of electrification and we use this cable for track circuits, automatic blocks, C.T.C., telephony and so on.

"There was a question about a co-ordinating authority from the C.T.C. point of view. We count that everything concerning the running of trains should be centralised to the C.T.C. office, including the planning of work, which occupies the track in one way or another. The work itself will be executed by the department concerned. At our older mechanical plants the station staffs have done minor jobs such as the changing of lamps etc. The new fully automatic plants are more complicated (harder to trace the cause of faults) and therefore we place them entirely under the responsibility of the signal repairmen and have a system of periodical maintenance that reduces the number of faults. To a large extent the station staffs as well will be abolished.

"The maintenance is divided into track-maintenance (232 areas with altogether 12,000 men), power system maintenance (55 areas with 1,300 men), signalling (64 areas with 1,300 men), and telecommunication (38 areas with 450 men).

"To the question of the President concerning the sound signal at the barriers I may mention that the bell is of special and very strong construction and we have had very good experience with it. Nothing is done to check that the bell is ringing when it should be ringing, but we have at least two bells at every level crossing."

The President, Mr. R. A. Green, in concluding the discussion said that it was a very pleasant duty to thank the author. He would like to congratulate him on four things. Firstly—a most interesting and clear Paper. Secondly, his courage in giving it to them in their own language. Thirdly, the extremely fine quality of his slides, and fourthly, for the way he had answered his questioners. He thought it was a very fine performance to put up in a strange land among—in some cases—strangers. He was sure they could go on asking Mr. Knall questions, and he could go on answering them, but there was one question he would like to ask, and that was on the barriers, which he had admitted was a very difficult problem. Mr. Knall had mentioned in the Paper a sound signal at the barriers, and he presumed that took the form of a bell. Was that a special type of bell, or was it just an ordinary type of bell; and was anything done to prove that the bell was, in fact, ringing when it should be ringing, or would ring if it were asked to ring? This was a problem that was present in Great Britain on level crossings and very important pieces of signalling equipment are involved.

He was also interested to see that they still had a private railway in Sweden, which he understood was fitted with C.T.C., so he thought there was still hope for our Bluebell Line yet!

Concluding the President said it was his very pleasant duty to ask them to accord a hearty vote of thanks to Mr. Knall for giving them such an interesting Paper that evening. This was carried with acclamation.