Telecommunications and computing before the internet: British Railways' nationwide train operating system

Jonathan Aylen, University of Manchester
Bob Gwynne, Llangollen Railway, Denbighshire

The internet is built on packet switching: small units of information are sent from node to node in a telecommunications system and re-assembled at their destination. Before the internet there were large centralised computer networks based on circuit switching over telephone lines. An end-to-end circuit was kept open for transmission of data.

The Total Operations Processing System (TOPS) adopted by British Rail during the mid-1970's is one example of an area wide telecoms linked computer network. The shift to computer based control of freight using TOPS was part of a long history of control and computation on the railways. British Rail used its own telephone system to run a nationwide hub-and-spoke information system. Their signalling staff helped manage the transition to a digital railway with innovations such as multiplexing, modems and desktop computers.

The US computer hardware and software for TOPS had its origins in American Cold War air defence initiatives. Ultimately, a centralised system was vulnerable. The advent of packet switching allowed a more decentralised approach to network design and IBM was side-lined by this disruptive change in technology. Yet TOPS was adapted to the new distributed architecture using packet switching and remains in use as legacy software.

Keywords: TOPS; SAGE; Chain Home; Packet Switching; Circuit Switching; Multiplexing; Modem; Mini-computer; Mainframe; Technology Transfer

Introduction: Telecomms and Early Computing

The internet is built on packet switching: small units of information are passed from node to node and re-assembled at their destination.[1] But, before the internet there were large, area wide computer communication systems based on circuit switching of telephone lines. An end-to-end circuit needed to be kept open throughout the entire transmission of data.[2]

UK defence and nationalised industries such as electricity and gas were pioneers in nationwide, large-scale circuit switched private communication systems.[3] Here we explore just one system that was a precursor to the internet, operated by publicly owned British Rail. This system adopted innovations such as computer-to-computer communications and multiplexing which were building blocks for the later internet. It ran on British Rail own countrywide telephone system.

In turn, British Rail's national computer-based train operating system in the 1970's was developed from an american air-defence system. The British Rail TOPS system used "command and control" architecture with hub-and-spoke circuit-switched communications. The rigid design of TOPS stands in contrast to the subsequent evolution of the internet as a decentralised, packet switched network. TOPS is unusual as it made the transition to packet switching and still underpins train information, for instance on mobile 'phones. "TRUST" – "Trains Running System TOPS" – is at the heart of all recorded train movements in the UK. TOPS evolved with technology into the era of distributed networks, packet switching and internet protocols.

The TOPS computer system was implemented by British Railways to monitor and control its freight traffic from August 1973 onwards. By Autumn 1975 TOPS kept track of *every* freight train, loco and wagon and their movements across the whole British Rail network, working in real time. For the first time, British Rail knew where its freight assets were and what they were doing. TOPS achieved a complete shift in the management of goods traffics from a system based on paper, telephone calls and traditional practices to universal computer input via telecommunications.

This paper shows how the American SAGE military air defence system evolved into the civilian TOPS system, first at Southern Pacific Railroad in California and then on much larger scale at British Rail. SAGE was a centralised air defence system which responded to radar warnings of Soviet bomber attacks on the USA. In the same way, TOPS was an "early warning system" for British Rail freight trains.[4] For the first time, marshalling yards knew what train was arriving. It demonstrates the impact of the military priorities on early systems architecture and the way in which techniques such as multiplexing and real time computing diffused from US defence into the unlikely context of British Rail freight.[5]

The Total Operations and Processing System

TOPS stood for "Total Operations and Processing System". The complete system was officially inaugurated on 27th October 1975.[6] TOPS allowed British Rail to keep tabs on its freight rolling stock using IBM 370 mainframe computers and disk memory storage installed at Marylebone in London. Information was generated and received at over 150 Area Freight Terminals across Britain. By 1975 all these offices were equipped with pioneer mini-computers – Datapoint 2200 version 2 machines with 12K of memory, a built-in green screen visual display and two tape cassette decks. They were universally known as "Ventek" machines as the overall terminal system including card punch/reader, printer and interface cards was known as Ventek 9200.[7]

Communications were circuit switched between computers over British Rail's own telephone network using frequency division multiplexing.[8] In this fashion a large number of messages could be sent side-by-side down the same telephone line. Modems converted local digital data to analogue signals for fast onward transmission. These signals were then demodulated, or "de-muxed", and converted back to digital at

Marylebone. British Rail's expertise in signalling and telecommunications drove these two radical innovations of computer to computer transmission and multiplexing.

The software for the TOPS system ran on "middleware" called TOPSTRAN, an assembler based macro language which used IBM macros to call-up files and handle instructions and data.[9] Because the system was circuit switched, each message was preceded by a telephone number – a TOPS LATA, a "Line Address Terminal Address". For instance, the LATA for the Central Wagon Authority at Room 201, BR Headquarters, in London was C172900.[10] The system also allowed ZZ text messages between terminals, a precursor to e-mails and also a focus of much entertainment as well as communication.

TOPS was a massive data handling operation. By 1976, TOPS was controlling up to 4,500 freight trains and 100,000 wagon movements each day across 11,000 miles of track via the Area Freight Terminals across the UK and at Dunkirk and Zebrugge in Europe. Every type of cargo, every siding and every wagon was coded into the database.

The Defence Background to Computer Communications

Military design shaped the *pre*-internet communications environment. The military influence is hardly surprising. The US Department of Defense funded almost three-quarters of american industrial R&D spending in sectors such as electronics and aerospace during the early Cold War.[11]

TOPS shows the links between defence electronics and civilian use of technology. Here we explore the hinterland between telecommunications and computing during the Cold War, and in particular, "command and control" architecture based on centralised hub-and-spoke communications architecture.

To understand the defence background to TOPS, we need to show the importance of SAGE – the US military "Semi-Automatic Ground

Environment" – in driving progress in computing and advancing the interaction between computers and telecommunications. SAGE was a centralised air defence system which provided a response to radar warnings of Soviet bomber attacks on the USA. The evolution of the SAGE military air defence system of the US into the TOPS civilian system first at Southern Pacific in the USA, and then at British Rail shows the impact of military priorities on early systems architecture.

Command and Control - Chain Home to SAGE

SAGE itself was a direct descendent of the British World War 2 Chain Home radar warning system.[12] Chain Home worked through voice telling over dedicated landlines the plots of enemy aircraft detected by radar to a centralised filter room. The tracks of incoming aircraft were displayed on a tracking table, sifted and refined for accuracy. These tracks were transferred to a centralised control room where a second tracking table allowed fighter aircraft to be deployed to intercept hostile attacks.

Chain Home was slow moving and labour intensive.[13] It required considerable skill to evaluate overlapping plots, calculate the ground range of the target, cope with the peculiarities of each radar station and determine the best interception. It was also difficult to integrate fighter cover and anti-aircraft defence of the same airspace.

At the beginning of the Battle of Britain, RAF Stanmore was filtering the returns from 57 operational radar sites around the coast of the UK. At its peak in May 1944, the Chain Home system was receiving reports from 208 radar stations and labour shortages became acute.[14] Speed of response was not so crucial in an era of propeller driven aircraft.

After the Second World War, the US Defense Department appreciated a swifter "quick reaction" response was needed towards faster moving jet aircraft, especially as the threat was of greater magnitude in a nuclear era. There were likely to be multiple points of attack. To add to the confusion, civil air traffic was growing rapidly in US airspace, adding more tracks to the radar. Early Warning Radar systems needed to probe out to longer range, greater heights and establish the size and nature of incoming attacks. Early Warning Radar Systems needed to work with fewer people - faster.

The Tizard Mission from the UK to the United States in 1940 gave fresh impetus to US radar developments and agreement that the US would focus on particular development projects.[15] The US Radiation Laboratory – "Rad Lab" went on to develop servo-controlled gun directors integrated with radar sets.[16] The success of automatic radar controlled anti-aircraft fire control was demonstrated from the Anzio beach-head in Italy from February 1944 onwards. The US system was built on the Radiation Lab's SCR-584 radar and Bell Labs' M9 potentiometer based Gun Director combined with proximity fuzes in the noses of the shells.[17] The achievements of automated gun control suggested a systems approach to air defence harnessing computers was the way forward. If servo-mechanisms could shoot down V-1 flying bombs, surely computer based systems were the way to supplement human perception, decision making and responses for air defence in the jet era?

From Cape Cod to SAGE

The idea of an air defence system managed by a digital computer was first trialled on the "Cape Cod system", which came into operation in September 1953.

> "The system was the first large-scale, real-time control system that combined remote sensing and complex control operations, all controlled by a central digital computer and supervised by human operators." .[18]

The Cape Cod system was built around a temperamental prototype digital computer called Whirlwind based at MIT in Cambridge, Massachusetts .[19] Radar data was sent across eastern Massachusetts on leased 'phone lines working at voice bandwidth using amplitude modulated signals from a

World War 2 vintage Microwave Early Warning radar at Hanscom Field, at Bedford, Massachusetts. [20]

The role of the Whirlwind digital computer was to collect target reports from the radar network, transform the various reports onto a common set of co-ordinates, continue to perform automatic tracking based on radar reports at 10-12 second intervals, and calculate computer trajectories for interceptor aircraft. Initial tests in April 1951 showed it was possible to collect and process data and calculate an interception, at least for slow, propeller driven aircraft flown by the local Air National Guard Unit. This "proof of concept" showed the system would work in principle, and construction of the full prototype "Cape Cod System" was ordered three days later.

More up-to-date radar, dedicated 'phone lines, larger, more reliable random access memory on Whirlwind, and the development of "interactive" display consoles were just some of the factors which improved reliability and showed computer controlled air defence to be feasible within two years and five months of the go-ahead for the full-scale trial.

The Whirlwind computer has taken the limelight. But, it is important to emphasise the revolutionary telecommunications developments used in the second stage of the Cape Cod experiment. A decision was made to process radar signals at source before onward transmission, instead of transmitting the radar video image to the computer.[21] This made much better use of the available telecommunications bandwidth. A machine known as Fine Grain Data (FGD) was developed. This separated radar echoes in to their individual component pulse returns and the target position was determined as a weighted average of these separate pulses. The coordinates of this target and time of occurrence were then stored in binary form on a multiple track magnetic drum. Two 1,300 bit per second analogue circuits were used to transmit this data to the digital computer. This was arguably one of the first applications of a modem – a device for converting digital data from a computer into analogue form for transmission over a conventional ‘phone line.[22]

In addition, radar returns and height information from height radars was stored by the Fine Grain Data machine and transmitted over the same two circuits using time-division multiplexing. This approach, using modems and multiplexing, was adopted throughout the SAGE system and was to play a key role in adoption of TOPS by British Rail 18 years later. As was anticipated at the time "Improved techniques arising from this military application will find application also for industrial users." [23]

The way was clear to develop an air defence system which would blanket the entire United States – The Semi-Automatic Ground Environment System - SAGE. This used 30 direction centres across the United States and Canada. Each centre was responsible for a Sector. Each centre building contained two IBM built AN/FSQ-7 valve based computers for processing the radar data – one computer for current operation and one for back-up.[24] Duplication of computers at each direction centre was an early example of fail-safe computer operations. The pair of computers worked in real time with a near seamless switch over between operating computer and back-up. Again this feature was to be replicated in British Rail’s TOPS system at their sector “centre” at Marylebone, in London.

Hub and Spoke

SAGE first came into military operation in June 1958 at McGuire Airforce base, New Jersey. SAGE is credited with transforming the US computer industry with a sequence of hardware, software and communication innovations and catapulting IBM into manufacturing leadership in the computer sector. [25] Key computing innovations were adopted by this giant project, ranging from magnetic core memories to time-sharing and the first widespread use of modems. SAGE also introduced a systems approach to the management of large projects. By 1959, the project employed *half* the software programmers in America. [26]

IBM were *not* responsible for the software for SAGE or the telecommunications, but they were responsible for the interface between telecommunications and the computer which was to prove crucial for TOPS. At its height, SAGE funded 7,000 to 8,000 IBM employees out of a US total of 39,000 in 1955.[27] The project taught IBM how to manufacture large volumes of mainframe computers, including crucial components such as ferrite core memories.[28] But, it also prompted IBM to develop software to handle telecommunications. IBM began to sell these skills integrating a mainframe computer with remote terminals via telecommunications equipment under the brand name "teleprocessing".[29] They were not the only seller of telephone links to computers. Nor were they the best. But they were the dominant firm in US computing. Teleprocessing set IBM off on a trajectory of developing telecommunications linkage of computers.

Cold War to Coal Trains

IBM's know-how was rolled out to the American Airlines SABRE booking systems.[30] Less well known is the extensive TOPS collaboration to develop a "teleprocessing System" to manage Southern Pacific's freight trains. The trade press commented at the time: "For IBM, suppliers of much of the hardware and software, TOPS represents a big opportunity to break ground in the lucrative area of transportation control." [31] TOPS was not so much "swords into ploughshares" as "Cold War to coal trains".

SABRE and TOPS were not the first use of a centralised computer for business data processing. The Lyons Company in the UK relied on daily orders 'phoned in from Lyons Corner Houses around the country. The Lyons Electronic Office computer, Leo 1, was developed to manage stock control for all their tea rooms, processing their orders overnight and despatching deliveries early the next day, as well as managing their extensive payroll.[32] Staff from Corner Houses around the country would wait for a 'phone call at pre-arranged times so that their order up-dates could be put on to punched cards. Some Corner Houses lacked telephones, so the manageress would take a chance on the local public 'phone box being available at the critical time for the incoming call.[33] While the Lyons experiment was revolutionary, it did not integrate computers and telecommunications. It was the "Chain Home" of business communication.

TOPS – Command and Control for Freight Trains

TOPS was developed in the USA through a collaboration between IBM and the Southern Pacific Railroad. Southern Pacific began a feasibility study for computer control of freight flows with IBM in June 1960 which was developed during the 1960's into a practical piece of software called TOPS by a subsidiary called Tops On-Line Inc., 80% owned by the Southern Pacific Railroad and 20% owned by IBM.[34] Southern Pacific formally bought a complete system for commercial use from its partner IBM at a cost of $21.5 million in 1966.[35] Included in this price was all the systems analysis, programming, communications facilities, hardware, and all of the on-line files. In total there were 700,000 lines of machine code instructions – not too dissimilar to the alleged one million lines of code for SAGE. The system was due on line by late-1970.

The overall "command and control" architecture of TOPS derived from the SAGE model. Looked at in detail, the bespoke TOPSTRAN software was essentially a set of IBM Macros which called forth the appropriate sub-routines and activated drives with the help of some assembler language.[36] The emphasis was on file handling to update and store data on the complete railroad operation. The whole freight data-base was managed by two IBM 360, model 65 computers at Southern Pacific's Market Street headquarters in San Francisco.[37] It was not used for train control. That remained the preserve of the railway operations side.

TOPS in the USA relied on telecommunications-to-computer interfaces developed on SAGE. These interfaces used binary digital data sent over telephone circuits in analogue form to the direction centres.[38] Early versions of TOPS implemented on North American freight railroads were constrained by point to point communication which tied up a single phone line whenever a single flow of data was being transmitted. Circuit switching requires the circuit to remain open all the time data is flowing. This was sufficient for US railroads accustomed to running one train a day from each freight yard. Southern Pacific also had its own extensive microwave telecommunications network. But, tying up a whole circuit to transmit one message would not work for a complex freight network like British Rail.

The Neglected Freight Railway in the UK

In the UK, British Railways freight operations were neglected for a decade after the Second World War. This was a time of rapidly growing competition from the road haulage sector. The motorway building programme started at the end of the 1950's. The first stretch of the M6 motorway – the "Preston by-pass" - opened on 5th December 1958.[39] Better roads reduced transit times for freight moved by lorry. The reliability and speed of diesel lorries improved too. De-regulation of lorry freight brought more direct competition. Road freight was also door-to-door - origin-to-destination, obviating the need for transhipment at railway sidings or freight depots before departure and on arrival. So the newly named British Rail faced acute competition for goods traffic by the 1960's.

British Rail had some 'fast' freight trains (where every wagon was fitted with a braking system controlled by the driver) with a maximum speed of 45 mph. But there were still many 'mixed' goods trains, with wagons having no more than a parking brake, and overall train braking reliant on the skill of the driver and guard working together. These "unfitted", mixed goods trains conveyed individual wagons from marshalling yard to marshalling yard across the country.[40] As might be expected, these trains did not travel quickly relative to road competition, nor was it easy to monitor goods once they were in transit, or keep them secure when being 'marshalled' in yards for onward movement. British Rail sought to preserve this wagon load traffic against competition from road lorries.

A struggle for control

Railways long struggled to control their complicated businesses and large physical networks. The railways were pioneer users of the telegraph which was in regular use from 1839. The first Hollerith machines were installed on the Lancashire and Yorkshire Railway by 1905 at their head offices at Hunt's Bank in Manchester.[41] This started a long association between computers and the railways. So it was logical that the post-World War II nationalised railway industry looked to computers to deliver significant change to the British Rail network between 1965 and 1975.

Contrary to its image, British Rail had extensive knowledge and experience of modern computing which had been applied at an early stage to pensions, payroll, timetabling, signalling and research. British Rail had already worked with a wide range of computer suppliers including, ICT/ICL (Crewe and Peterborough), Honeywell (Reading), IBM (Darlington), Ferranti and Elliott Automation. They also used analogue computers for research at Derby.[42]

British Rail also had huge skills in telecommunications with their own nationwide 'phone network. Their signalling staff already had experience with modern electronics such as multiplexing. [43] But, the enormity of the task of developing a computer based freight control system from scratch soon became apparent and British Railways started a worldwide search for an off-the-shelf solution. They had sufficient in-house skills to appreciate they could not do it by themselves. At the same time, they had the "absorptive capacity" to procure and adapt an off-the-shelf system for their own needs.

By the end of the 1960's almost every railway network worldwide was looking to computers as a way to manage their freight operations. The British Rail review team were heavily influenced by an ambitious computerisation scheme at Canadian National who had turned to

Southern Pacific in the USA for help following difficulties with their own in-house development.[44]

British Rail were keen to purchase TOPS from Southern Pacific as a software solution for the much bigger UK freight system. They had to overcome three obstacles: the political difficulties surrounding the purchase of American computer hardware and software, the problems raised by the sheer complexity of the British Rail system compared to the US railroad, and the need for on-line "real time" communications across a wide range of terminals.

British Railways Board approved the acquisition of TOPS in June 1971 and Government approval was obtained in October. British Rail then bought software and technical support from TOPS Online Services. [45] Jack Pfeiffer, from TOPS-Online became their Resident Manager in London from 1971 to 1976.

In principle, British Rail was bound by contract to slavishly copy all the American software and equipment. Some of the IBM hardware was obsolete and offered poor technical performance. British Rail soon gained the confidence to break parts of the contract, selling off their obsolete electro-mechanical IBM 1050 punch card terminals used at Area Freight Centres and replacing them with mini-computers of British Rail's choosing. Given the inadequate transmission speed, poor mechanical reliability and archaic design of the IBM terminals, TOPS Online Services were in no position to object. British Rail also adopted newer IBM technology for the communications controllers and used newly available 3330 disc drives.

British Rail's adoption of TOPS was as much a telecommunications revolution as a computing one. Southern Pacific Lines only ran 400 freight trains a day. British Rail ran 3,500 trains daily which meant much bigger data flows. British Rail's own national telephone network had been widely modernised during the 1960's with coaxial cable. [46] This extensive cable network had the advantage of providing alternative paths for data signals in the event of a link failing. For example, data from a TOPS terminal at Avonmouth could be switched to Marylebone either via Birmingham and Derby, or via Paddington. [47]

The twin technical breakthroughs in adoption of TOPS at British Rail were the use of modems at either end of the phone line which allowed digital data signals to be transmitted down an ordinary phone line in high speed analogue form and the ability to multiplex these signals, allowing up to eight separate data signals to be sent down the same line at once.

To explain: The number of separate signals which could be sent down one phone line depended upon the speed of data transmission. At 600 baud, a 'phone line would only allow *one* voice conversation. The TOPS data signals were sent from Ventek terminals at a speed of 200 baud – (or 134.5 baud from offices briefly equipped with early IBM 1050 punched card terminals.) This speed of transmission allowed for *eight* channels in an audio band.

These eight channels used by TOPS were separated by shifting the frequency on the audio carrier. This is analogous to tuning an old fashioned radio dial to select a radio station. The frequency of the eight channels went up in increments of 340 Hz. So the first channel frequency ranged from 850 Hz up to 1020 Hz (a range of 170 Hz). There was then a guard channel. The second began at 1190 - 340 above the first - and went up to 1360, and so on up to channel 8 from 3230 to 3400 Hz. [48] In this fashion eight messages could be transmitted simultaneously along a conventional British Rail trunk telephone circuits. This particular process of carrying multiple frames of data back-to-back down the same telephone line was known as "frequency division multiplexing" (FDM) or "frequency stacking" and was one of the breakthroughs needed to allow TOPS to work in the context of the British Rail telephone system.

The modems - supplied by Lenkurt Electric Company of San Carlos, California - took the slow speed direct current digital input from TOPS area offices and converted them into high speed alternating current analogue signals for onward transmission to Blandford House, Marylebone in London. At Marylebone, the data was converted back to direct current binary format for the computer. The process was reversed for outgoing messages from Marylebone to the Area Freight Centres.

These technical solutions conceal an elegant and cost-effective design. The particular modem used, a Lenkurt 25c, conditioned each data signal for transmission at a particular frequency slot on the telephone line. So the signal was frequency modulated *and* translated to analogue in one device.[49] A separate multiplexer was not needed. Frequency Division Multiplexing was arguably better for long distance, uninterrupted transmission. Time Division Multiplexing would have required a separate multiplexer.

TOPS allowed British Railways to keep tabs on its freight rolling stock across the whole rail network in real time using central computers at Blandford House, Marylebone in London. TOPS achieved a complete shift in the management of goods traffics from a system based on paper, telephone calls and traditional practices to universal computer input via telecommunications. Real time processing replaced human contact. TOPS not only brought a marked improvement in the use of assets, it also shaped the way in which the future railway would be organised and managed.

Domesday Book on disc

Adoption of computer control of freight required a systematic inventory of railway assets with a consistent numbering system. For the first time, there was a listing of every freight sidings, every operator, every wagon and loco and every cargo carried. The result was a veritable "Domesday Book" for the railway, kept on tiers of magnetic disks at Blandford House, Marylebone. [50] This data storage was formed of 32 IBM 3330 disc packs, each pack having a 100 Mb storage capacity reached by random access.

The TOPS system relied upon a feed of information from all the marshalling yards across Britain. In order to keep track of every train movement, TOPS divided the country initially into 152 Train Responsibility Areas (TRA's). This was a 24 hour operation as many goods trains move at night. TOPS Offices – officially known as "Area Freight Centres" - were established across the country from Inverness to Dover (and even abroad at Dunkirk and Zebrugge for train ferry traffic). These offices were data linked to the Marylebone computers using modems and British Rail's own telephone network. Local outlying sidings and marshalling yards were linked in to their Area Freight Centre using pioneering fax machines – one machine for transmitting and one for receiving.[51]

Details of each goods train would be supplied to the central computers using punched cards produced by the Ventek machines. In effect, each deck of cards would mimic the train itself, with a locomotive card at the front and individual cards for each wagon. In this fashion, the goods office would transmit the "consist" of each train to the central computers. The jargon "consist" revealed the American origins of the software – literally each train *consisted* of so many wagons. A train could not move unless its consist had been sent for updating on the central computer.[52]

The central computer would process information from area offices and send on the train consists to their next destination. For the very first time, freight managers knew what would be arriving at their yards. Customers were able to trace their freight consignment as it moved across the rail network, and in principle wagons couldn't go missing as frequently happened in the past. [53]

Punched cards and Portakabins

The first TOPS offices were given IBM 1050 terminals, but these were soon supplanted by Datapoint terminals, effectively small mini computers, which used unusual 96 character Ventek cards for coding data, arranged in three tiers of 32 6-bit characters. They were programmed using tape cassettes (which allowed for additional loading of elementary games!) [54]

The TOPS offices were located on remote marshalling yards. Half of them were specially commissioned Portakabins. Becoming a TOPS clerk was a heaven-sent opportunity for young British Rail clerks as it meant rapid promotion, overtime earnings and entry into the new field of computing.

The TOPS operating centre – Blandford House at Marylebone – was described as "space age" at the time.[55] It contained two IBM 370 main frame computers – briefly three when the peak "cutover" was taking place. The ground floor of Blandford House was devoted to communications. There were initially three 2703's multiplexors in use and three on standby. These were soon replaced by IBM's delayed 3705 pre-processors to help communications routines. [56] The first floor housed the "big iron" - the IBM 370 computers and all their back-up files on disc drives. One of these mainframes ran the system and one was available for immediate back-up. The top floor was given over to the programming team that translated the US software into working routines for British Rail. By 1976, TOPS was controlling up to 4,500 freight trains and 100,000 wagon movements each day across 11,000 miles of track via the Area Freight Terminals across the UK and at Dunkirk and Zebrugge in Europe. This amounted to a million freight train miles a week across the system.[57]

Implementation of TOPS was more akin to a military operation than a conventional BR project. [58] The organisation had a headquarters to itself, Blandford House, separate from the main British Railways Head Office next door. It had a clear leader - Bob Arnott, the project manager - and a specially recruited task force of staff including programmers, telecommunications experts and a training staff equipped with their own four-coach training train which moved around the TOPS Areas as they "cutover".

TOPS was implemented between August 1973 and October 1975. The first pilot "cutover" exercise took place in the Plymouth and St Blazey area, the China Clay district of Cornwall. This was a relatively isolated part of the UK network, having only one mainline connection out, but lots of freight movement within it. The summer weather was atrocious and the inspectors waded around the china clay terminals checking the details of the wagons in the rain while ankle deep in a "sea of Brylcreem"- wet, white kaolin.[59] By September 30th 1973 TOPS had taken over across the West Country.[60] The final cut-over was the North East – ironic given the large number of Geordies in the TOPS Team.

TOPS *worked*, and still works in modified form.[61] Every freight train ran under TOPS with the exception of some strategic cargoes during the Falklands War of 1982. There were teething problems at the outset due to duplicate wagon numbers, individual wagons having different numbers on each side and a failure to record all wagon movements in and out of yards. Audits gradually ensured full compliance.[62]

The TOPS system was soon modified and enlarged to include and survived privatisation. The central operation was moved to Crewe on Christmas Day 1987 and Blandford House in London sold off for property development. The TOPS system evolved into a distributed network using packet switching. Among its many additional tasks today is to log train operational data which allows for 'delay attribution', part of the way the privatised railway system works. This system is called 'TRUST' – Trains Running Under System TOPS.

Too Vulnerable

Technology development is often path dependent.[63] But every so often that path is disrupted by un-foreseen technical developments and social forces. Radical innovations - partly of military origin - were to shift telecommunications technology onto a new course with packet switching and the emergence of the internet. Centralised hub-and-spoke systems such as SAGE and TOPS were obsolete as originally conceived with the change from circuit switching to packet switching.

There is an evident flaw in the design of centralised command and control systems such as SAGE and the original TOPS. If Blandford House were to fail, the complete TOPS system across the whole of Britain would fail. To quote a joke of the operators at the time, it would have been a case not of TOPS, but "BOTTOMS" – "Back on to the old manual system". [64]

The US Department of Defense recognised that a well-placed nuclear strike could disable their whole preparation for war by knocking out central computer hubs. There was a need for a distributed system where capability was spread around.

It should be emphasised that a centralised system with point to point communication has many advantages. There is only one central point of reference, so there is no discrepancy between records in different file stores as one is up-dated, but not the other. It is secure and self-contained. Circuit switching uses reserved bandwidth for the entire transmission time and any break in transmission would be immediately noted. So, it is hard to hack.

The RAND Corporation, NPL and Packet Switching

The need for survivable communications in the event of a nuclear attack was recognised at an early stage of the Cold War. A flexible defence posture required continuing communication between political authorities after a nuclear exchange (Edwards, 1996, pp.131-3).[65] There was also a broader consideration of military strategy that defence is best *de*centralised as a local response to attack, rather than subject to central control.

The US response to the nuclear threat was the technical breakthrough of packet switching for telecommunications. There were many precursors to packet switching – the postal service for instance. But, in a brilliant paper finally released in 1964, Baran explicitly proposed a:

> ". . distributed communication network concept in which each station is connected to all adjacent stations rather than to a few switching points, as in a centralized system. The payoff for a distributed configuration in terms of

survivability in the cases of enemy attach directed against nodes, links or combinations of nodes and links is demonstrated". [66]

Baran summarises extensive work for RAND and outlines "simple switching mechanisms using an adaptive store-and-forward routing policy to handle all forms of digital data." [67] The idea was that the process would be so swift the message would seem to arrive almost instantly. This solved the previous problem with "store and forward" systems where messages tended to accumulate at congested nodes in a network, like parcels at a Christmas postal depot.

At the same time, at the National Physical Laboratory in the UK, Donald Davies was proposing packet switching for a more innocent commercial reason: to help free up line capacity – in effect, a form of telecommunications time-sharing.[68] It is said that a member of the Ministry of Defence broke the news to Davies that his novel idea was already current in US defence research.[69] Arpanet and the UK EPSS first generation packet switched networks began to be specified by the late 1960's, but it was to take many years before CCITT standards emerged and packet switching became the technology of choice.

The development of packet switching as an alternative to circuit switching is a complex subject, overlain by the messianic fervour of its advocates.[70] It is an example of "interpretive flexibility" – a technology that can be shaped by social forces to mean different things to different groups. Developed from military necessity and a desire to run programmes on computers located elsewhere, it was to spawn the internet. But no one can claim that was the intention.

Packet switching has two inherent advantages – robustness and better use of bandwidth. Circuit switching of the sort used by TOPS was in pervasive use for data transmission up until the end of the 1960's. Since data tends to be sent in short bursts, over 90% of the circuit time was idle. Yet packet switching, which allocated bandwidth dynamically, was technically complicated for data traffic. In some respects, the complicated technology didn't matter, as in the early days, the producers of the technology were also the users, so they could just figure it out.[71]

Ironically, British Rail had a "STRAD" store and forward message switching system prior to adoption of TOPS which routed their telex services in the London Midland Region.[72] STRAD stood for "Signal Transmit Receive And Distribute". This was built by STC and installed around 1964 in Mercury House, Crewe. It worked at 50 baud across the transmission and cable network of BR. It remained in use until the 1980's when it was replaced by the National Teleprinter Network.

Conclusion

TOPS was criticised at the time. *New Scientist* (1971) claimed it was too expensive, saying that "British Rail had chosen to go first class with its new computer system, even though other railways have found that second class gets you there for less money".[73] They went on to argue: "TOPS is a product of the early 1960's computer euphoria. Its basic assumption is that you can control anything if only you can collect enough information and store the data in a large enough computer." *New Scientist*'s narrow focus on technology missed the point. The aim was a transformation in the managerial culture of British Railways. And the system worked.[74]

In many respects TOPS was a sophisticated patch on a struggling system. Individual wagon load freight from "anywhere to anywhere" was abandoned in 1984 in favour of "Speedlink" which grouped together wagons into segments to make up into trains which could follow a common route, avoiding any marshalling yards *en route*.[75]

In some respects, TOPS is a requiem to the first generation of telecommunications-computer networks – "the end of the line" for hierarchical command and control systems. Yet, British Rail's TOPS system is *still* working 50 years after initial adoption. TOPS evolved into the era of distributed networks, packet switching and internet protocols. The legacy core system has been continuously modified by the addition of interrelated software packages covering areas such as locomotive maintenance and passenger operations. The TRUST system – "Trains running under System TOPS" underpins passenger information available on mobile 'phones. So TOPS made the transition from centralised command-and-control architecture to a distributed network.

The shift to computer based control of freight using the TOPS system at British Rail during the mid-1970's should be seen as part of a history of control and computation on the railways. Adoption of TOPS was a shift from a traditional railway based on custom and practice to a network using centralised control and information systems. The US computer hardware and software for TOPS had its origins in American Cold War air defence initiatives supplied by IBM. But ultimately, a centralised system was vulnerable. The advent of packet switching allowed a more decentralised approach to network design and IBM was side-lined by this disruptive change in technology. But TOPS adapted to the new distributed architecture helped by adoption of packet switching. In that respect it continues to be part of the long history of the interplay between telecommunications and computers.

Footnotes

1. On the distinction between packet switching and circuit switching and much more besides see the clearly written K.G. Beauchamp, *Computer Communications*, London: Chapman and Hall, 2nd edition, 1990

2. Precursors to the internet have been overlooked by scholars. Two valuable exceptions are: Martin Campbell-Kelly and Daniel D. Garcia-Swartz, "The history of the internet: the missing narratives", *Journal of Information Technology*, vol.28, (2013), issue 1, pp.18-33 and a sceptical treatment from Hans Dieter Hellige, "From SAGE via Arpanet to Ethernet: Stages in computer communications concepts between 1950 and 1980", *History and Technology*, vol.11, no.1, (1994), pp.49-75

3. These systems were – *and still are* – shrouded in secrecy as part of critical national infrastructure. The UK's Cold War defence network is among the best documented. For the General Post Office's "Backbone" defence network developed from 1956 onwards see

Peter Laurie, *Beneath the City Streets*, Harmondsworth, Penguin, 1972, pp.217-234 and The National Archives, CAB 134/1207, *Ministerial Committee on Civil Defence:* Official Committee: Meetings 1-3; Papers 1-23, 1956 Mar 5-Oct 30, Memorandum, Serial No.12, dated 26.7.56, "Backbone radio link and radio standby to line links for safeguarding vital communications", note by the Joint Secretaries.

In this context, "radio" refers to telecommunications transmission via microwave radio relay. Microwave radio relay was a communications technology developed during the 1960's. It relied upon a narrow beam of microwaves to carry messages across a line-of site between a tightly focussed transmitting antenna and a precisely aligned receiver. British Rail used this technology for telecommunications between York and Newcastle between 1964 and 1989 despite strong GPO opposition. Southern Pacific Railroad had an extensive microwave network, some 6,200 miles long covering eleven States.

The British Gas and Central Electricity Generating Board systems were both switched over lines leased from GPO/BT. See Ron Hildrew, "Central Control", *British Gas Review*, vol.1, no.3, (Spring 1975), pp.4-6 and U.G. Knight and F. Moran, "The operation and control of the CEGB power system", *Transactions of the Institute of Measurement and Control*, vol.6, no.5, (October 1984), pp.237-246

British Rail's TOPS system is summarised in: J.S. Andrews, *A General Description of T.O.P.S.*, Derby: British Rail Research, Internal Memorandum, Report Reference IM SE 5, File No. 262-345-5, August 1982

4. TOPS was an "early warning system" for the British Rail freight trains. As an operator said once TOPS was implemented: "No longer does anything arrive like a bolt from the blue" (p.13), see "All Lines On-Line: TOPS is now in full operation", *Rail News*, no.149, (November 1975), pp.1, 8, 1-13, 16. TOPS was not a new concept. The idea of centralised traffic control on the railway can be traced back to a system introduced on the Midland Railway in 1909.

5. "Despite their origins in a culture marked by secrecy, many cold war-era developments in science and engineering remained exclusive accessories to the defense establishment only temporarily. From system analysis to satellites to think tanks, these innovations soon were adopted and adapted for civilian applications in both public and private sectors."
Jennifer S. Light, *From Warfare to Welfare: Defense Intellectuals and Urban Problems in the Cold War,* Baltimore: Johns Hopkins University Press, 2003, p.7

6. The key history is Robert Arnott, *TOPS: The Story of a British Railways Project*, London: British Railways Board, 1979. Otherwise, ". . things like TOPS form an almost 'secret' railway history which most people will never hear." James at

http://www.rmweb.co.uk/community/index.php?/topic/18211-hypothetical-steam-tops-numbers/page-2, last accessed 5th April 2019

7. These mini-computers were selected after a thorough evaluation by Dr Richard Maddison. See Arnott, *ibid.*, pp.35-36 and personal communication and interview with Dr Maddison, (1st and 5th August 2019.)

8. John Boura was telecommunications engineer for the TOPS Project. See J. Boura, "The telecommunications network for the T.O.P.S. project", *Institution of Railway Signal Engineers*, Paper 3.1.73, (1973), pp.153-169 and J. Boura, "Data communications for a Modern Railway", *Institution of Railway Signal Engineers*, Paper 30.10.75, (1975), pp.30-42

9. The authors are deeply indebted to Margaret Willmot for a comprehensive explanation of the software of TOPS. She worked for British Rail as a programmer on TOPS at Blandford House from 1973 to 1976.

10. TOPS, *Wagon Distribution Manual, Area Manager Edition*, London: BR Blandford House, mimeo, 25 August 1974, page A.01 – private copy. We are very grateful to an anonymous but valuable source for an explanation of the workings of TOPS before and after the advent of packet switching. We are indebted to Michael James for advice on ZZ messages (Communications 7th, 8th February 2022).

11. Stuart W. Leslie, *The Cold War and American Science: The Military-Industrial-Academic Complex at MIT and Stanford*, New York: Columbia UP, 1993, pp.1-2

12. See Michael Bragg, *RDF1: The Location of Aircraft by Radar Methods 1935-1945,* Paisley: Hawkhead Publishing, 2002 and Colin Dobinson, *Building Radar*, *Forging Britain's Early-warning Chain,1939-45,* London: Methuen, 2010. Although adoption of radar was by no means a foregone conclusion, see Phil Judkins, "Making vision into power: Power struggles and personality clashes in British radar, 1935-1941", *International Journal for the History of Engineering and Technology*, vol.82, no.1, (January 2012), pp.93-124

13. Labour shortages were one reason why the decision was taken during wartime in November 1943 to cut back Chain Home stations, with some placed on a care-and-maintenance basis and some dismantled altogether.

14. We are indebted to Squadron Leader Mike Dean for maps and an explanation of Chain Home

15. S.S. Swords, *Technical History of the Beginnings of Radar*, London: Peter Peregrinus for the Institution of Electrical Engineers, 1986, p.120

16. David A. Mindell, “Automation’s finest hour: radar and system integration in World War II”, in Thomas P. Hughes and Agatha C. Hughes (eds.), *Systems, Experts, and Computers: The Systems Approach in Management and Engineering, World war II and After*, Cambridge, Mass.: MIT press, 2000, pp.27-56 and D. A. Mindell, *Between Human and Machine: Feedback, Control, and Computing Before Cybernetics*, Baltimore: The Johns Hopkins University Press, 2002

17. David A. Mindell, "Automation's Finest Hour: Bell Labs and Automatic Control in World War II", *IEEE Control Systems*, vol.15, issue 6, (December 1995), pp.72-80 and Russell W. Burns (2006), “The Evolution of Modern British Electronics, 1930-1945”, *Transactions of the Newcomen Society*, vol.76, pp.221-234

18. C. Robert Wieser, “The Cape Cod System”, *Annals of the History of Computing*, vol. 5, no. 4, (October 1983), pp.362-369, see p.369

19. Kent G. Redmond, and Thomas M. Smith, *From Whirlwind to Mitre: The R&D Story of the SAGE Air Defense Computer*, Cambridge: MIT Press, 2000

20. R. G. Enticknap and E.F. Schuster, "Sage data system considerations", *Transactions of the American Institute of Electrical Engineers, Part I: Communication and Electronics,* vol. 77, no.6, (1959), pp.824–832

21. Enticknap and Schuster *ibid*; John V. Harrington, “Radar Data Transmission”, *Annals of the History of Computing*, vol.5, no.4, (October 1983), pp.370-374

22. Robert R. Everett, Charles A. Zraket and Herbert D. Benington, “SAGE – A Data-Processing System for Air Defense”, *Annals of the History of Computing*, Volume 5, Number 4, (October 1983), pp.330-339

23. Enticknap and Schuster *op.cit.*, p.831

24. Robert R. Everett, Charles A. Zraket and Herbert D. Benington (1983), “SAGE – A Data-Processing System for Air Defense”, *Annals of the History of Computing*, Volume 5, Number 4, (October 1983), pp.330-339

25. Redmond and Smith, *op.cit.*; Paul N. Edwards, *The Closed World: Computers and the Politics of Discourse in Cold War America*, London: MIT Press, 1996; Thomas Hughes, *Rescuing Prometheus*, New York: Pantheon Books, 1998; David F. Noble, *Forces of Production: A Social History of Industrial Automation*, New York: OUP, 1986, chap.3;The centralised nature of the system is highlighted by *United States Air Force, In Your Defense: The SAGE System* https://www.youtube.com/watch?v=06drBN8nlWg, *circa* 1960 downloaded 7th November 2023. Hellige *op.cit.* points out the shortcomings of SAGE have not been

documented, nor have a sequence of civilian failures of centralised systems that followed in its wake.

26. Martin Campbell-Kelly, *From Airline Reservations to Sonic the Hedgehog: A History of the Software Industry*, London: MIT Press, 2003, p.39

27. Kenneth Flamm, *Creating the Computer: Government, Industry and High technology*, Washington D.C.: Brookings, 1988, p.89

28. Emerson W. Pugh, *Memories that Shaped an Industry: Decisions Leading to IBM System/360*, Cambridge, Mass., MIT Press, 1984

29. Campbell-Kelly, *op.cit.*, p.41; IBM's rivals in linking computers included members of the "Seven Dwarfs" such as Burroughs, CDC, GE and later DEC, see Richard Thomas DeLamarter, *Big Blue: IBM'S Use and Abuse of Power*, London: Macmillan, 1986, ch.16

30. Charles J. Bashe, Lyle R. Johnson, John H. Palmer and Emerson Pugh, *IBM's Early Computers*, Cambridge. Mass.: MIT Press, 1986, ch.12. In turn, SABRE prompted its own trajectory of airline software development. Here too, IBM had its rivals.

31. Warner Kramer, "Control is TOPS at Southern Pacific", *Control Engineering*, vol.13, no.11, (November 1966), pp.91-93, see p.91. For a complete 454 page outline see: IBM-Southern Pacific, *System Design Report - Total Operations Processing System*, March 1962, IBM Tele-Processing Systems and Southern Pacific Company joint report, 1962 http://www.bitsavers.org/pdf/ibm/tops/TOPS_SystemDesignReport_Mar62.pdf, (downloaded 2nd August 2018).

32. Gordon R. Gibbs, "The LEO 1", *Datamation*, (May 1965), pp. 40-41; David Caminer, John Aris, Peter Hermon and Frank Land, *User-driven Innovation: The World's First Business Computer*, McGrawHill, 1996

33. Ralph Land, "Lyons Teashops", pp.221-226 in Caminer *et al.*, ibid., see p.223

34. IBM-Southern Pacific, *op.cit.* IBM collaborated with outside software teams as this helped channel orders for lucrative hardware sales. IBM's ownership share seems to have later passed to Strong-Wishart & Associates, transportation management consultants.

35. Kramer, *op.cit.*

36. A macro is an instruction that makes a sequence of pre-programmed instructions available to the computer via a simple statement. Hence it is called a “macro” because a large set of instructions can be expanded from one simple “micro” statement.

37. Southern Pacific also had four smaller System/360 model 20’s located at each of four zone accounting offices. These were used for local off-line processing of freight bills as well as on-line, high-speed, input-output to the TOPS system. Otherwise the railroad relied on punch cards for data entry at a local level.

38. Enticknap and Schuster *op.cit.*

39. Peter Merriman, “Motorways and the Modernisation of Britain’s Road Network, 1937-70”, in Ralf Roth and Colin Divall (eds.), *From Rail to Road and Back Again? A Century of Transport Competition and Interdependency*, Farnham: Ashgate, 2015, pp.315-338

40. Michael Rhodes, *From Gridiron to Grassland: the Rise and Fall of Britain’s Railway Marshalling Yards*, Sheffield: Platform 5 Publishing, 2016

41. Robert Gwynne, “A long engagement – railways, data and the information age”, *Science Museum Journal*, (Autumn 2021), https://dx.doi.org/10.15180/211603

42. Among those who helped unravel the long history of British Rail computing are Brian Bushell, Mick Haynes, Ray State and Dr. Alan Wickens.

43. Time Division Multiplexing was used for signalling systems as early as 1958, but the volume of data flowing was tiny. See Regional Editor, London Midland Region News, “Remote Control Signalling”, *British Railways Magazine*, vol.9, no.10, (1958), pp.271-273 and Geoffrey Kichenside and Alan Williams, *Two Centuries of Railway Signalling, Revised Second Edition,* Alderstone, Surrey: Oxford Publishing Co., 2016, ch.14.

44. "CN reorganises for real-time computer control", *Railway Gazette International*, vol. 127, no.2, (February 1971), pp.54-57; Arnott, *op.cit.*, p.2.

45. Arnott, *op.cit.* is silent on the purchase. Ken Green recalls "I had to sign in the contractual agreements that eventually became about an A4 book this thick. I specified the changes that had to be made to the Southern Pacific application. . . . they made me sign and initial every page of that document." (Interview with Brian Clementson and Ken Green, Derby, 10th June 2019).
Until August 1971 TOPS was known as “Freight Information & Transit Control System FITCS” within British Rail – far less catchy. See TNA, AN 167/22, vol.13, *British Railways Board: Board and Committee Minutes and Papers Reports to the Board No.13*.

46. Boura,1973, *op.cit.*, fig.9. On the advantages of coaxial cable see Beauchamp *op.cit.* For a map of the network see R. Arnott, R.J. Day, & W.K.H. Dyer, "TOPS equipment", *Railway Engineering Journal*, (September 1975), pp.109-11, figure 3. Lines from Area Freight Centres were put through a "combiner" to make full use of the trunk network.

47. Boura, 1975, *op.cit.*

48. Boura, 1973, *op.cit.,* fig.7. A good explanation is provided by *Bits Bytes and Bauds: Telecommunications for TOPS*, film made by Neilson Baxter and British Rail, 1974 at: http://www.samhallas.co.uk/railway/bbb.htm (last accessed 29th November 2023)

49. See "Modems, those unglamorous but vital 'black boxes' that form the interfaces between digital machines and the communications networks", *GTE Lenkurt Demodulator*, (a monthly trade newsletter) October 1974, pp.2-7. We are indebted to Sam Hallas for advice on Modems. Also see http://www.samhallas.co.uk/railway/bbb/hardware.pdf (downloaded 5th October 2018)

50. Arnott, Day and Dyer *op.cit*., p.110. There were five sets of files covering: all locations on the rail network, the locomotives used, all the wagons, all the trains and the working timetables used to allocate the track. On the IBM3330 "merlin" disk drives see Emerson W. Pugh, Lyle R. Johnson, John H. Palmer, *IBM's 360 and Early 370 Systems*, MIT Press, 2003, chapter 9

51. These pioneering Mufax Courier machines were made by Muirhead & Co.

52. In the event of IT problems causing delays it was said the solution was to give the train crew £5 and send them off to the pub until the snags were sorted out and their train could depart. While it may be apocryphal, it captures the relaxed culture of freight operations which preceded TOPS.

53. Including two lost bullion wagons: Charles Meacher, 'The Rise and Fall of Marshalling Yards', *BackTrack*, vol.1, no.1, (Spring 1987), pp.9-14

54. Les Martin, (Interview 29th January 2021) spoke of a "table-tennis game" for Ventek minicomputer terminals. He told the story of someone coming to collect a much needed boot-up tape to revive a Ventek terminal machine, only to realise when they got to the TOPS Office they picked up the table-tennis game instead. Keith Collyer spoke of two more games played on Ventek terminals, one a quiz based on Douglas Adams science-fiction classic "Hitchhiker's Guide to the Galaxy" and one based on Asteroids. (Interview with Keith Collyer, former maintenance engineer for Ventek machines in British Rail TOPS Offices 1979-1982, Worsley, 10th January 2020.)

55. Quote from Bruce MacDougal, 6th April 2018

56. Ken Green said “they were huge, huge boxes” (interview, Derby, 10th June 2019). **T**his new equipment still used the older TCAM (Telecommunications Access Method) for hard-wired telecomms. BR did not fully adopt VTAM (Virtual Telecommunications Access Method) IBM’s new standard until they moved TOPS to Crewe during 1987. See DeLamarter, *op.cit.*, chap.17. The system at Blandford House used IBM’s MFT (Multi Tasking – Fixed Tasks) Operating System to control the routing of messages, edit the messages and get the computer to call up all the relevant files. So the “front end processing” software had both a telecoms role and a computer role. Since it was IBM equipment it used EBCDIC interface standards instead of ASCII.

57. Arnott, *op.cit.*, p.113

58. Constantine Andriopoulos and Patrick Dawson, *Managing Change, Creativity and Innovation*, London: Sage, 2009, pp.65-69 includes a well-informed case study on TOPS.

59. Laurie Hall, ‘Who would an Implementer be!’, *TOPICS*, (February 1975), no.2, pp. 5-6. TOPICS was an in-house newsletter issued by Blandford House during implementation of TOPS.

60. Railway Gazette International (1973) "TOPS takes over in the West of England", *Railway Gazette International*, vol. 129, no.10, (October), pp.392-395

61. The metamorphosis of TOPS into a modern, all encompassing management information system deserves a separate paper. Suffice it to say that TOPS-CICS, a version of IBM’s best-selling CICS software introduced in 1969 was part of the early transition to a Crewe based, packet switched, web-based IT system for the rail network which went on to survive the switchover to privatisation. For an introduction to CICs, see Campbell-Kelly *op.cit.*, chap.5. As Dave Fidal said “TOPS did what was required. You could draw a box around it.” He made the point: Telecomms was changing but the computer software remained the same. (interview with Dr David Fidal and Ivor Lewis, Manchester, 24 May 2019).

62. These audits make entertaining reading. The Area Manager Radyr in Wales berates his supervisors about the “deterioration in checking and reporting procedures.” A second memo complains “Guards, Shunters, Chargemen, Train Meeters” fail to check their trains and give correct information. He reports:

> “A recent physical check at Maerdy Colliery showed 187 wagons on hand; the computer showed 199 – a difference of 12 wagons – not quite; that was the difference in the total number of wagons; there was also quite a divergence in the wagon states.”

Other audits are more positive. See "memos from the Area Manager Radyr" dated 17th October 1980 to all Supervisors, National Railway Museum, Search Engine Archive, *Item 2006-7462, Collection of documents and papers relating to British Rail's Total Operations Processing System (TOPS) for the computerised controlling of traffic, circa 1973 to 1979.* "IBM Equipment" filing reference LAHH/TOPS/F102.

63. Nathan Rosenberg, *Exploring the Black Box: Technology, Economics and History*, Cambridge University Press, 1994, Part 1

64. I owe this to locomotive designer David Elliott, Darlington Locomotive Works, 31st July 2017. He attributed this joke to the British Rail Control Office in Leeds in 1975. (follow-up correspondence 2nd August 2017)

65. Edwards, *op.cit.*, pp.131-3

66. P. Baran, "On distributed communications networks", *IEEE Transactions on Communications Systems*, vol.CS-12, no.1, (March 1964), pp.1-9

67. Baran, *ibid.*, p.1

68. Martin Campbell-Kelly, "Data Communications at the National Physical Laboratory (1965-1975)", *Annals of the History of Computing*, vol. 9, issue: 3/4, (1987), pp. 221 – 247

69. Janet Abbate, *Inventing the Internet*, Cambridge, Mass.: MIT Press, 1999, p.27

70. For example, Lawrence G. Roberts, "Computer Report III: Data by the packet: Because computing costs are now so low, an unusual new concept of data communications is feasible ", *IEEE Spectrum*, vol.11, no.2, (February 1974), pp.46-51

71. Abbate *op.cit.*, ch.1

72. STRAD is another unknown railway story. The author is indebted to correspondence with David Haverson, (22nd October 2018); Clive Kessell, (27 October 2018) and Andrew Jones, (29th November 2020) for helping piece it together. Peter Robbins who was the deputy Telecoms Engineer for the Region was said to be the mastermind behind the whole project.

73. New Scientist, "Technology review: Expensive management program for BR rolling stock", *New Scientist*, (16 December 1971), p.160. The failure of other railway computer systems, for instance in West Germany, remains undocumented.

74. Ted Strong, "Concerns/problems we faced in implementing TOPS on British Rail", *NRM Review*, (Spring 2000), pp.22-23 provides a US management perspective on why it

worked. The implementation of TOPS and why TOPS worked and other systems failed will be the subject of a follow-up paper.

75. C.R. Anthony and B. Rogers (1989), *Rail Freight – today*, Yeovil: Haynes Publishing Group, 1989, ch.10

Notes on Contributors

Jonathan Aylen is senior visiting research fellow at the University of Manchester and a former President of the Newcomen Society for the Study of the History of Engineering and Technology. His recent research has specialised in the development of Cold War technology with papers on Britain's first atomic bomb and on the development of the Argus 200 computer for both the Bloodhound 2 guidance system and ICI chemical plant.

Correspondence to: jonathan.aylen@manchester.ac.uk
ORCID: Jonathan Aylen **iD** http://orcid.org/0000-0003-3015-6586

Bob Gwynne is a former Associate Curator at the National Railway Museum, York where he researched the considerable history of computerisation on Britain's railways. He is author of books on the Flying Scotsman and on Railway Preservation in Britain and articles on aspects of railway history. He frequently appears on television as a technical expert on railways. Bob is now Environmental and Sustainability Officer at the Llangollen Railway Trust.

Acknowledgements

This paper is part of a wider project on TOPS. Among the many signalling engineers, computer experts, radar specialists and railway personnel we must thank for unstinting help here are Chris Beckett, Peter Beevers, Brian Bushell, Brian Clementson, Keith Collyer, Mike Dean, Dave Fidal, John Godfrey, Ken Green, Sam Hallas, Mick Haynes, Michael James, Phil Judkins, Ivor Lewis, Bruce MacDougall, Dr Richard Maddison, Les Martin, Ray State and Margaret Willmot among many others.

An earlier version of this paper was delivered as the Burns Lecture to the Defence Electronics History Society (DEHS), Swindon. We are grateful to DEHS for permission to use some of that material here.

The authors alone remain responsible for the remaining errors, we hope not too egregious.

Archive Sources

The main archive source is National Railway Museum, Search Engine Archive, Item 2006-7462, Collection of documents and papers relating to British Rail's Total Operations Processing System (TOPS) for the computerised controlling of traffic, circa 1973 to 1979. The authors are indebted to the staff at NRM, including Alison Kay, Peter Thorpe and Angelique Bonamy for their sustained help.

Figure 1 Britain's Chain-Home radar system was the precursor to centralised command and control air defence systems (image courtesy of Mike Dean.)

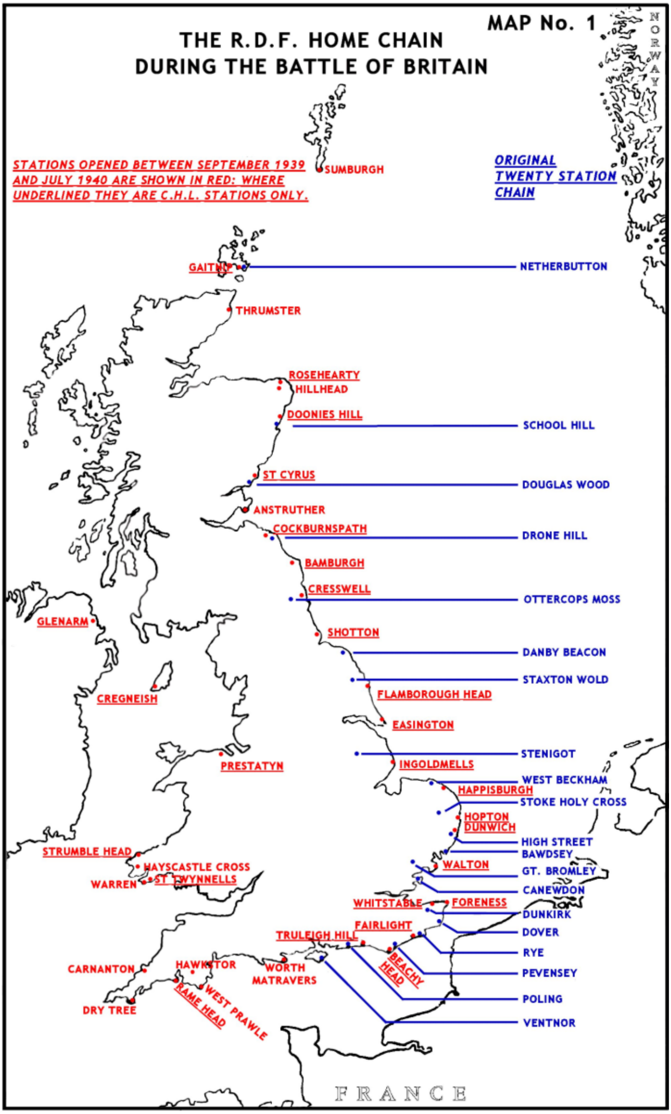

Figure 2 Use of radar and analog computers to direct anti-aircraft fire helped make the case for computer controlled air defence systems in the USA. An M-10 Gun Director, 1944

Figure 3 The Semi-Automatic Ground Environment (SAGE) for US air defence drew on the early success of the Cape Cod experiments. (Enticknap and Schuster, 1959, p.828)

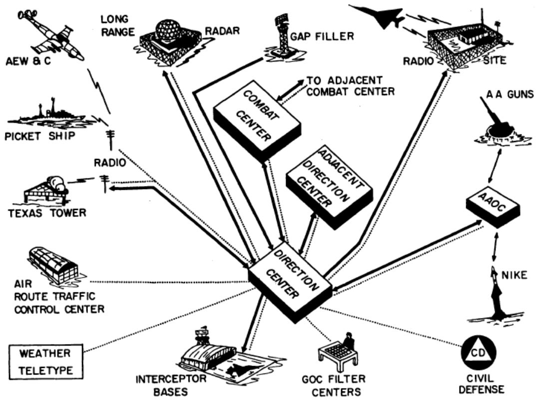

Fig. 5. Typical SAGE sector

—— Data circuits .... Other circuits

Figure 4. TOPS was the application of centralised command and control architecture to the British Rail freight system (The Railway Museum)

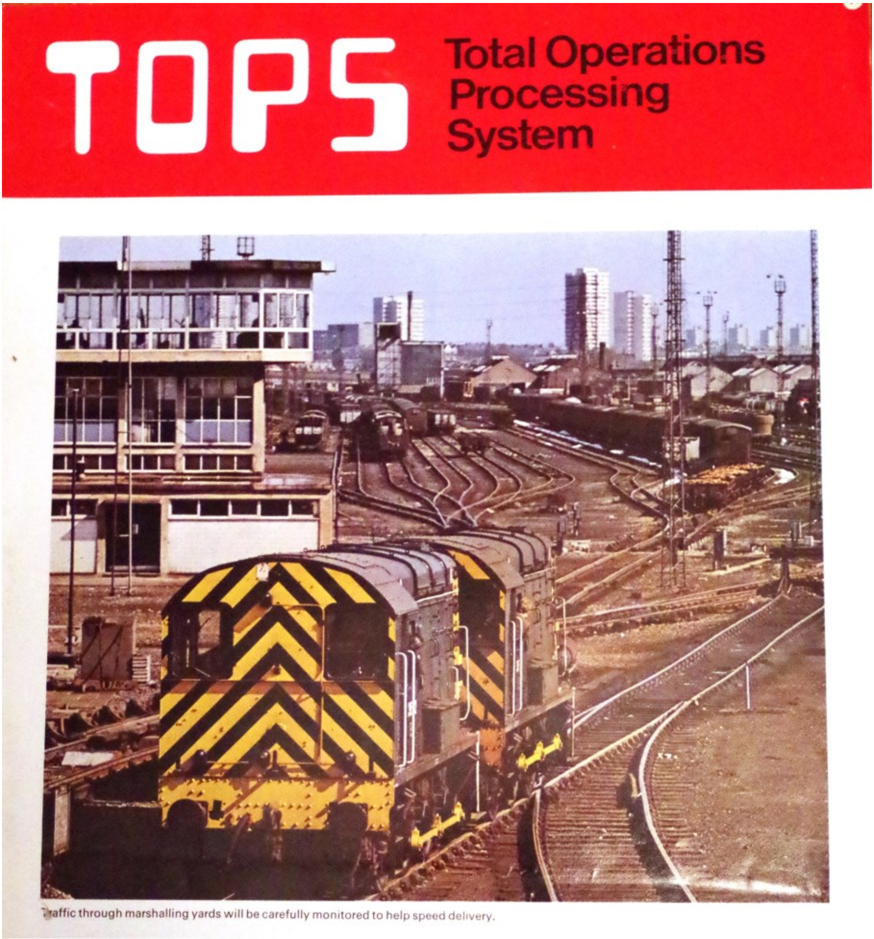

Figure 5. Wagon load freight was traditionally shunted at marshalling yards on the basis of custom and practice. Examining wagon labels at Tinsley, Yorkshire (The Railway Museum)

Figure 6. Blandford House at Marylebone, the TOPS headquarters, was space age in its day. (The Railway Museum)

Figure 7. Area Freight Centres used minicomputers to help transmit and receive TOPS information. Note the small CRT screen and two cassette tape drives on top. The purpose built desk conceals the interface equipment in the “tank”.

Figure 8. Half the Area Freight Offices were in Portakabins located on remote railway sidings across Britain (The Railway Museum)

Figure 9 Front End Processing of TOPS messages for the IBM mainframes took place on the Ground Floor Control Room of Blandford House

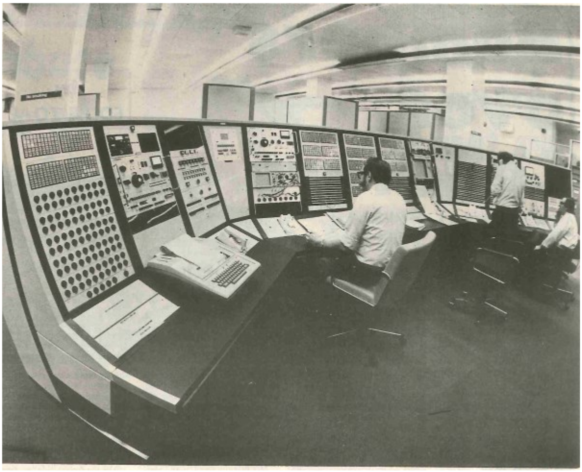

Figure 10 The Lenkurt 25C Modem was one of the technical developments in telecommunications transmission which made adoption of TOPS by BR possible (photo Sam Hallas)